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## Quarterly Technical Summary

General Research

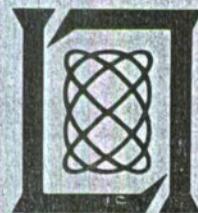
15 May 1965

Prepared under Electronic Systems Division Contract AF 19 (628)-500 by

**Lincoln Laboratory**

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



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## Quarterly Technical Summary

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### General Research

15 May 1965

Issued 16 August 1965

## Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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## INTRODUCTION

This is the first Quarterly Technical Summary on the General Research Program at Lincoln Laboratory, M.I.T.; it consolidates the material formerly published in the Quarterly Progress Reports of Divisions 2 (Data Systems), 3 (Radio Physics), 4 (Radar), 7 (Engineering), and 8 (Solid State).

The objective in making this change is to provide a more usable and efficient document, one that better shows the relationships among the General Research activities at this Laboratory.

Accepted for the Air Force  
Stanley J. Wisniewski  
Lt Colonel, USAF  
Chief, Lincoln Laboratory Office

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## DATA SYSTEMS DIVISION 2

### INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1965 for the General Research Program of Division 2. Separate progress reports on the Ballistic Missile Re-entry Systems, Project Apollo, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick  
Head, Division 2  
S. H. Dodd  
Associate Head

## DIVISION 2 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1965

### PUBLISHED REPORTS

#### Technical Report

TR No.				<u>DDC and Hayden Nos.</u>
377	An Experimental On-Line Data Storage and Retrieval System	J. F. Nolan A. W. Armenti	3 February 1965	DDC 615658

#### Technical Notes

TN No.				<u>DDC</u>
1965-13	Aspects of Associative Processing	J. A. Feldman	21 April 1965	614634 H-644
1965-18	Some Iterative Methods Using Partial Order for Solution of Nonlinear Boundary Value Problems	H. S. Witsenhausen*	14 May 1965	615658 H-650

#### Journal Articles<sup>‡</sup>

No.			
2331	Evaluation of Likelihood Functions for Gaussian Signals	F. C. Schweppe	IEEE Trans. Inform. Theory <u>IT-11</u> , 61 (1965)
2492	Lorentz Microscopy of Small Ferromagnetic Particles	M. S. Cohen	<u>J. Appl. Phys.</u> <u>36</u> , 1602 (1965)

#### MS No.

1165	Thickness Dependence of Creep Switching in Magnetic Films	G. P. Gagnon T. S. Crowther	<u>J. Appl. Phys.</u> <u>36</u> , 1112 (1965)
1186	Lorentz Microscopy of Small Ferromagnetic Particles	M. S. Cohen	<u>J. Appl. Phys.</u> <u>36</u> , 1060 (1965)
1187	Spin-Wave Effects in Magnetic-Film Switching	K. J. Harte	<u>J. Appl. Phys.</u> <u>36</u> , 960 (1965)
1189	Uniaxial-Anisotropy Spectrum in Nonmagnetostriuctive Permalloy Films	D. O. Smith G. P. Weiss	<u>J. Appl. Phys.</u> <u>36</u> , 962 (1965)

\* Author not at Lincoln Laboratory.

† Not yet assigned.

‡ Reprints available.

Division 2

Published Journal Articles (Continued)

MS No.

1215 Longitudinal Kerr Effect Using a D. O. Smith J. Appl. Phys. 36, 1120 (1965)  
Very Thin Fe Film

\* \* \* \* \*

UNPUBLISHED REPORTS

Journal Articles

JA No.

2353	Magneto-Optical Scattering from Multilayer Magnetic and Dielectric Films	D. O. Smith	Accepted by Optica Acta
2411	The Scaling of Digital Differential Analyzers	H. K. Knudsen	Accepted by IEEE Trans. Electron. Computers
2465	A Simple Local Sufficiency Condition Based on the Second Variation	P. L. Falb	Accepted by IEEE Trans. Automatic Control
2596	The Lorentz Force	M. S. Cohen	Accepted by Proc. IEEE

Meeting Speeches\*

MS No.

701A	Getting Human Judgment into a Computer	D. B. Yntema	Colloquium, Hanscom Field, Bedford, Massachusetts, 24 February 1965
1200	A Magnetic Film Memory Development Program	J. I. Raffel	International Symposium on Techniques of Memories, Paris, 5-10 April 1965
1206	Content Addressed Memory Using Magnetoresistive Readout of Magnetic Thin Films	M. L. Naiman	Intermag Conference, Washington, D.C., 21-23 April 1965
1229	Lorentz Microscopy of NiFe Films	M. S. Cohen	
1234	The Effect of Cu Diffusion on the Magnetic Properties of NiFe Films	T. S. Crowther	
1259	Magnetic Measurements with Lorentz Microscopy	M. S. Cohen	
1231B	The Ritz Method in Optimal Control	P. L. Falb	Applied Mechanics Colloquium, Bell Laboratories, Whippany, New Jersey, 4 March 1965

\* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Unpublished Meeting Speeches (Continued)

## MS No.

1259A	Lorentz Microscopy of NiFe Films	M.S. Cohen	
1284	Introduction	J.I. Raffel	
1285	Magnetic Configurations and Testing	A. H. Anderson	
1286	Film Properties and Preparation	T.S. Crowther R. Berger	
1287	Spin-Wave Theory of Magnetic-Film Switching	K.H. Harte	
1288	Fabrication and Facilities	T.O. Herndon E.A. Guditz	Industrial Liaison Symposium, M.I.T., 4 March 1965
1289	Associative Memory Development	M. Naiman	
1290	Optimizing the Longitudinal Kerr Effect	D.O. Smith	
1291	Uniaxial Anisotropy Spectrum in Permalloy Films	D.O. Smith G.P. Weiss	
1292	Circuitry	C.E. Woodward R. Johnson	
1296A	Some Current Work in the Borderland Between Perception and Memory	D.B. Yntema	Colloquium, Swarthmore College, 7 April 1965
1314	A Nanosecond Monolithic TTL Gate	P. Spiegel* R.L. Luce*	Solid-State Circuits Conference, Philadelphia, 17 February 1965
1333	APEX — A Lincoln Laboratory Approach to Man-Computer Cooperation in Problem Solving	J.W. Forgie	Communication Sciences Colloquium, University of Michigan, 18 March 1965
1348	Recognition and Detection: A Thurstonian Approach	W.P. Harris	Eastern Psychological Association, Atlantic City, New Jersey, 22-24 April 1965

\* Author not at Lincoln Laboratory.

# DIGITAL COMPUTERS

## GROUP 23

### I. COMPUTER SYSTEMS

#### A. TX-2 Modifications

Most of the major equipment changes in the TX-2 computer, described in earlier quarterly reports, have been completed and the new equipment placed in use. The design of the automatic block transfer control for input-output devices has also been revised to decrease device selection time. This work is approaching completion.

The principal effort on the TX-2 main frame during the last quarter has been devoted to taking advantage of the speed of the new 2- $\mu$ sec main memory modules. The basic cycle time for the main frame has been reduced from the 4.4- to 6.5- $\mu$ sec values for the original core memories to 2.4  $\mu$ sec for the new memories. This new value includes the time required for a SPAT cycle. Work will continue in the next quarter to remove the timing anomalies caused by the (comparatively) slow index memory system.

#### B. Symbolic Page-Address Transformation

The symbolic page-address transformation equipment\* has been installed and has operated successfully in the TX-2 computer since December 1964. This is the first-known operational two-stage dictionary address transformation scheme, although a number of comparable commercial systems will be available next year.

The parameters of the TX-2 transformation have been re-evaluated in the light of developing supervisor system experience. A user program ordinarily consists of a number of files. The overall operational efficiency of the system can be improved considerably by increasing the number of user program books (or segments) which can be addressed at one time so that only one file per book is ever required. This reduces the supervisor overhead substantially. The SPAT parameters will therefore be altered to allow 16 books of 8000 words (16 pages) a book, rather than 4 books of 32,000 words (65 pages). The design of the supervisor program will be considerably simplified, without a corresponding increase in hardware complexity. This change will also permit the control bits, which monitor and restrict the ways in which core storage are used, to be rearranged for further refinement in the supervisor program. This modification will be made the first month of the next quarter.

### II. CIRCUIT DEVELOPMENT

#### A. UHF Switching Transistors

##### 1. Measurements

Design and construction work is continuing on the final version of the automatic  $f_t$  plotter.

\* Division 2 Quarterly Progress Reports for 15 February 1964 and 15 February 1965, DDC 432493 and 612541, respectively.

## Division 2

Initial measurements show that the high-current anomalies in  $r_b'$  and  $C_c$  both begin at the same collector current, independent of frequency, in the range from 30 to 750 Mcps. The magnitude of the effect does appear to vary with frequency. This investigation will continue.

### 2. Contact Problems

Some instances of open electrodes have occurred in certain silicon transistors used by Group 63 in the Space Communications Program. These units employed gold thermocompression wedge bonds on aluminum pads. Investigation revealed that "balled-up" aluminum and purple plague contributed to weak bonds. These transistors have now been redesigned to make use of nail head bonds. A lead test apparatus has been fabricated and used to test the new bond design. Testing revealed that in all production units, the leads broke before the bonds. Purple plague, however, continues to be a problem.

## B. Integrated Devices

### 1. Lead Connection

The most recent DTL circuits now employ aluminum wire as well as pads with ultrasonic bonding to eliminate purple plague. Opening these packages has invariably left the circuit attached to the base of the package and the external leads attached to the cover. The interconnecting wires, rather than the bonds, have failed in each case.

A sectioning and staining facility has been set up to enable more complete evaluation of these circuits.

### 2. Hybrid Circuits

A six-transistor section of a standard current-mode circuit has been fabricated using six 2N2475 chips with 1-mil gold wire interconnections on a T0-5 header. This circuit performed slightly better than its discrete component counterpart.

### 3. Tester

A flexible, accurate, DC parameter tester has been built for testing all incoming integrated circuits. Of the elements already tested on this machine, seven out of 123 low-level RTL elements (gates, buffers, and expanders) failed to meet the vendor's specifications. No failures were recorded for 40 DTL elements.

## C. Circuit Applications

Several new plug-in units have been designed and built for the TX-2 computer. Typically, the new units are more than three times as fast as the old TX-2 equivalent units and will be used in critical areas of the TX-2 which are to be speeded up. The T-2 automatic tester has been updated to enable testing of these new units.

A new crystal-controlled master clock has been designed and is now operating in TX-2. The arithmetic element test unit has accumulated 5400 hours of operation without a failure. The integrated address circuitry in the LCM film tester has been running for sixty days without a failure. Another set of address circuits for the cross-section film memory has been

built which uses low-level RTL. A third addressing system is being designed around Diode Transistor  $\mu$ -Logie.

Several additions to the TX-2 computer are being designed using integrated circuits. After a thorough evaluation of various types of integrated logic circuits, diode transistor logic in flat packages has been selected as the best compromise for speed, logic flexibility, reliability, availability, and economy. These circuits will be mounted on conventional double-sided plated-through-hole etched-wiring cards 4-1/8 inches long  $\times$  4-9/32 inches wide. Up to twenty circuit packages will be connected by reflow-soldering the leads directly to wiring tabs on the top of the card.

The first major applications of these cards will be in the memory multiplexer and in a new clock-timer input-output unit for TX-2.

Work on the interfacing circuits between TX-2 negative levels and DTL positive levels continues.

### III. MAGNETIC FILM ENGINEERING

#### A. Clean Room

The clean room is in full operation and all systems associated with substrate cleaning are functioning as designed. Further experience with the clean room and associated equipment is necessary before the full effect on substrate cleanliness can be assessed, but inspection to date indicates that glass cleanliness has greatly improved.

#### B. Pattern Scribing

Experimentation with scribing materials continues. A number of metals, evaporated on glass, as well as organic coatings, have been evaluated. At this point, Kodak K. P. R. and evaporated chromium appear to offer the best possibilities.

#### C. Magnetic Film Characteristics

Coils for a B-H hysteresisgraph have been installed in the large vacuum chamber, making it possible to monitor and control  $H_e$  during annealing. When the desired values have been obtained, the heater is turned off, stopping further copper diffusion. The room temperature  $H_e$  is always approximately 50 percent higher than  $H_c$  at 300°C. This is in agreement with earlier work.\*

#### D. Content-Addressed Memory

Evaluation of film deposition parameters to provide large birotation and mismatch-to-match signal ratios is continuing. Inverted films with dispersion less than 2° have been made; although their match signals are too high for our needs, they should be excellent for ordinary memory applications. A new technique is being evaluated for the elimination of edge walls.

---

\* A. Segmüller, Z. angew. Phys. 13, 154 (1961).

#### **E. Large Capacity Memory**

An automatic position decoder for the optical comparator inspection device is being constructed. This will expedite the notation of faults in the word lines.

Three diffused-copper word substrates with different values of dispersion and  $H_c$  were tested at a few bit positions in the open structure. All had satisfactory digit current margins. Two hundred and twenty bits were tested on one substrate; all were good.

The million-bit prototype is being assembled with some of its electronics, primarily to test circuitry and noise-balancing schemes.

#### **F. Saturable Shielding**

Experiments have confirmed that a high-permeability film can be used to shield another film from the effects of an applied magnetic field. The spatial distribution of the shielding effect agrees well with that calculated from a mathematical model. This saturable shielding effect presents the possibility of all-magnetic word selection in film memories by providing an added threshold for the film input-output characteristics.

### **IV. SYSTEM PROGRAMMING AND APPLICATIONS**

#### **A. Associative Processing**

A compiler for an associative processing language has been completed. The language is running on a simulated associative memory for TX-2 and is described in Lincoln Laboratory Technical Note 1965-13. The current version is being expanded to use on-line displays as the principal communication medium. Further development of the associative language has been suspended pending completion of the generalized translator, VITAL.

#### **B. Graphics**

The investigation into conic curves and surfaces, reported last quarter, disclosed the possibility of using a projective transformation of a parabola to draw conic sections. A display generator using this principle has been planned which would be capable of drawing any first- or second-order curve and which could easily be extended to third-order curves. Further development depends upon reasonably priced analog multipliers. A device is being studied which uses the magnetoresistance effect in permalloy films to produce an output voltage which is the product of three input currents. The film and drive lines are capable of being arranged in arrays for performing matrix multiplication with one assembly. Linearity and operating frequency appear to be satisfactory.

# COMPUTER COMPONENTS

## GROUP 24

### I. MAGNETIC FILMS

#### A. Magneto- and Electro-optics

Practical structures have been designed which optimize the performance of magneto-optical light switches in metallic ferromagnetics.<sup>1</sup> By using the "mirror" generated at a boundary at which total internal reflection occurs, a magnetic film very thin compared with the optical wavelength, and a simple dielectric-film structure to accomplish dual-mode impedance matching, the longitudinal Kerr effect can be improved by approximately an order of magnitude over the optimum performance of semi-infinite magnetic material.

An experimental investigation of the optical properties of metallic ferromagnetic films so thin as to be discontinuous has been started in an attempt to improve the basic magneto-optical rotation to optical loss ratio. Results have been quite encouraging.

The theory for electro-optical thin-film light switches has also been worked out. The efficiency should be higher than for the magneto-optical switches because of the availability of lower-loss electro-optical matrices (e.g., ZnS). The advantages of thin-film electro-optical switches over their bulk-material counterparts would be low-voltage operation and small size, factors which would be of particular importance in potential computer applications.

#### B. NiFeAl Alloy Films

Work continues on the study of NiFeAl alloy films. Results so far have shown a surprisingly strong oblique-incidence effect: when enough Al is added to decrease the magnetization to approximately one-quarter of the no-Al value, the oblique-incidence anisotropy is sufficient to overcome the field-induced anisotropy and the easy axis is rotated by 90°. This phenomenon occurs even at incidence angles less than 5°. The oblique-incidence effect for NiFe is negligible at such angles.

#### C. Annealing of Permalloy Films

The change of  $H_K$  during perpendicular anneal can now be monitored continuously and automatically by means of an electronic feedback loop and a sensing current which utilizes the magnetoresistance effect. The power of this instrumentation in elucidating the anisotropy spectrum of permalloy films is expected to be very great. Initial measurements at 100°C have already revealed the existence of three distinct anisotropy processes.

#### D. Theory of Magnetization Ripple

##### 1. Longitudinal Magnetostatic Field

Calculation of the hitherto neglected longitudinal magnetostatic force has been completed. Its effect on the ripple spectrum is most conveniently expressed as a field  $H_L$ , which in equilibrium is parallel to the mean magnetization. To a close approximation, this field is given by

a constant  $H_{11}$  (independent of wavelength) for ripple components with wavelengths less than  $4\pi L$  ( $L$  = half-thickness of film), and by another constant  $H_{12}$  for components with wavelengths greater than  $4\pi L$ . We find that  $H_{11}$  is proportional to the mean-square magnetization dispersion  $\delta^2$  and exceeds the exchange field of ripple components with wavelength  $4\pi L$  provided  $\delta > \delta_1$ , where  $\delta_1 \propto L^{-1}$ . For a 1000-Å permalloy film,  $\delta_1 \approx 3^\circ$ , and for  $\delta = \delta_1$ ,  $H_{11} \approx 30$  oe.

Of greater importance is  $H_{12}$ , since it is the long wavelength ripple components which contribute to the dispersion and to dynamic effects.<sup>2</sup>  $H_{12}$  exceeds the exchange, uniform anisotropy, and external fields of these components provided  $\delta > \delta_2$ , where  $\delta_2 \propto L^{1/2}$ . For a 1000-Å permalloy film,  $\delta_2 \approx 2^\circ$ , so that even though ripple amplitude may be small, longitudinal magnetostatic forces cannot necessarily be neglected.

The dispersion  $\delta$  has also been calculated. Whereas in the absence of longitudinal magnetostatic forces  $\delta$  was found to vary as<sup>2</sup>  $K_1 r_o$  ( $K_1$  = mean local strain-induced anisotropy,  $r_o$  = mean crystallite size), we now find, for  $\delta \gg \delta_2$ , that  $\delta \propto (K_1 r_o)^{2/5}$ . Thus the increase in dispersion with increasing local anisotropy of increasing crystallite size is sharply curtailed.

## 2. Mean Ripple Wall Spacing

The apparent mean wavelength  $\lambda$  of ripple walls, as observed by Lorentz electron microscopy, has been calculated. One finds that  $\lambda$  is, in general, not the same as the exchange wavelength  $2\pi\lambda_e \sim 1\mu$  (Ref. 2). For the normal case of  $\lambda_e \gg r_o \gtrsim L$ ,  $\lambda = 2\pi r_o$ , and it is not until the crystallite size exceeds the exchange length ( $r_o > \lambda_e$ ) that we find  $\lambda = 2\pi\lambda_e$ . However, as ripple amplitude increases, the effective value of  $\lambda_e$  is reduced by longitudinal magnetostatic forces, so that the transition from a wavelength proportional to crystallite size to a wavelength independent of crystallite size may occur at crystallite diameters of less than 2000 Å.

## II. ELECTRON TRANSPORT

### A. Contact Potential During $\text{Al}_2\text{O}_3$ Growth

The difficulties with reproducibility mentioned in previous quarterly reports have been avoided by proper aging of the reference electrode and by studying the work function changes of plasma oxidation rather than thermal oxidation. Reproducibility is good to within about  $\pm 0.030$  volt under optimum conditions. The measurements indicate that the work function of oxidized aluminum is always greater than that of fresh aluminum. No change in work function would be expected for the simple case of a thin layer of oxide with no surface dipole layers and no intrinsic field.<sup>3</sup> If the surface dipoles are zero, the work function change from the fresh aluminum is equal to the voltage across the growing oxide. The observed increase in work function is consistent with the negative outward voltage acting to accelerate positive aluminum ions toward the surface in qualitative accordance with the Mott theory of oxidation.<sup>4,5</sup> A pronounced time dependence of the work function is also observed for very thin oxide layers. The above-mentioned increase in work function becomes progressively smaller after exposure to the plasma. This is consistent with oxygen reacting with the aluminum ions as they arrive at the surface and steadily reducing the Mott potential. For thicknesses of oxide greater than or equal to a thickness required to produce a good tunnel diode ( $\approx 20$  Å), the above time effects disappear. This, too, is consistent with the Mott theory in that the field which aids aluminum ion transport drops to the point where no further ions leave the aluminum and the work function undergoes no further change.

Diodes produced during the plasma treatment have a symmetrical 1.8-volt barrier in contrast to the asymmetrical thermally grown diodes of Pollack.<sup>6</sup> Work function measurements during thermal growth may illuminate the source of this discrepancy. Barrier height determinations are made easier by measurements at liquid nitrogen temperature because of increased diode breakdown voltage.

### B. Thin-Film Metal-Metal Oxide Triode

A thin-film Al (emitter) -  $\text{Al}_2\text{O}_3$ -Al (gate or base) -  $\text{Al}_2\text{O}_3$ -Al (collector) triode has been constructed and shown to have power gain. The gate or base Al film is  $\sim 100 \text{ \AA}$  thick and the  $\text{Al}_2\text{O}_3$  barrier layers are  $\sim 20 \text{ \AA}$  thick. The most extensive measurements have been made at liquid nitrogen temperature in order to improve the breakdown characteristics. At this temperature, the differential collector efficiency  $\alpha = (\partial i_c / \partial i_e)_{V_{cb}}$  has a peak of 0.77 at  $V_{cb} = 1.4$  volts and  $V_{eb} = -1.4$  volts. The power gain PG can be calculated from

$$PG = \frac{1}{4} \alpha^2 \frac{r_c}{r_e}$$

where  $r_c$  and  $r_e$  are the dynamic collector and emitter impedances. A near optimum value of PG occurred at  $V_{cb} = 1.3$  volts,  $V_{eb} = -1.6$  volts, at which point

$$\alpha = 0.6$$

$$r_c = 660 \text{ kohms}$$

$$r_e = 13 \text{ kohms}$$

$$PG = 4.7$$

The physical mechanisms by which the device operates are thought to be a combination of: (1) tunnel emission and hot-electron collection through the base and over a potential barrier at the collector, (2) tunnel emission directly from the emitter to the collector through holes in the base layer, where control is by field modification when voltage is applied to the base. The details of the device characteristics and theoretical interpretation are currently under study.

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1. D. O. Smith, accepted by Optica Acta.
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4. N. F. Mott, Trans. Faraday Soc. 35, 1175 (1939).
5. N. F. Mott, Trans. Faraday Soc. 36, 1 (1940).
6. S. R. Pollack and C. E. Morris, J. Appl. Phys. 35, 1503 (1964).

# PSYCHOLOGY

## GROUP 25

### I. APEX

Work continues on the APEX system, which will share TX-2 among several on-line users. A primitive version that time-shares the computer is working and is being expanded almost day by day as routines that have been checked out in isolation are merged with those currently in operation. It is beginning to serve as a vehicle for debugging the library and service programs.

#### A. Status of APEX

A few routines have yet to be written, but most of the coding has been completed and tested in isolation. The current primitive version allows time-sharing of two user programs provided: (1) they fit into core memory, (2) their input-output requirements are limited to typewriters and to one-at-a-time use of the Xerox printer.

This version includes the typical functions planned for the complete system: CALLING a program via a translator, GOING UP to a higher MAP to execute it, and PEELING BACK to the translator when the program is finished. A primitive HELP function has also been implemented to facilitate troubleshooting in users' programs. Thus enough of the system is now operating to permit the checkout of a wide variety of service routines, library routines, and users' programs.

The main areas that still require substantial efforts are the Core Storage Allocation Routine (CSAR) and the routines for particular input-output devices. A temporary CSAR is in use in the current system with substantial amounts of work remaining to be done on: (1) an efficient algorithm for allocating and retrieving real core, (2) the responses to the various boundary alarms that the user can generate, including the alarm that automatically enlarges a so-called expandable file, (3) the ability to handle synonyms, and (4) the responses to some of the less basic calls for service and information.

#### B. Service and Library Routines

With a primitive system available as a vehicle for debugging, there is an accelerating amount of work on service and library routines that are not strictly speaking parts of APEX itself. The following routines (some of which have been produced with the cooperation of Group 23) are in operation or nearing the completion of checkout:

- (1) A basic translator for on-line commands in a simple language.
- (2) A conversion routine for handling the input and output of numbers.
- (3) A package of routines that allow on-line examination and modification of memory registers and machine-state words.
- (4) Memory-dump routines for the Xerox printer.
- (5) A package of routines to facilitate on-line entry and retrieval of items stored in the user's directory.
- (6) A floating-point arithmetic package for doing simple arithmetic on scalars that are named and remembered in the user's directory.

## II. HUMAN INFORMATION PROCESSES\*

### A. Discrimination of Recency

A methodological experiment on the ability to discriminate which of two pictures had been seen more recently was performed by using the procedure and the pictures described in the last quarterly progress report. The method gave stable results. Two similar forms of the test, using different pictures, were administered at an interval of 48 hours. No significant differences were found between tests, between sessions, or between parts of a session.

As had been expected, there were few instances in which the subject failed to recognize whether he had seen the pictures. Thus the equal-discriminability scale of recency obtained from this experiment is unusually free from contamination by failures of recognition.

### B. Short-Term Recall

Two additional studies of the effects of time and intervening activity on short-term recall have been completed. The first study was an investigation of the recall of lists of five words when the intervals between successive presentations and between the final presentation and the test were filled with the task of adding numbers, or with the task of classifying numbers as odd and even. Recall was higher when the intervening task was classifying. With the adding task, the number and kind of errors in recall were essentially the same as with the number-reading task described in the last report.

The second study attempted to reverse the observed improvement in recall that results from increasing the time between two presentations of a list. The second presentation was reduced from the time required to read the list aloud to a time of 0.9 or 0.5 sec. When the second presentation was reduced to 0.5 sec., recall decreased as time between presentations increased.

### C. Keeping Track of Several Things at Once

The task of keeping track of several things at once<sup>†</sup> has been examined further. An earlier experiment had investigated the effects of forced rehearsal on the subject's ability to remember the current states of six variables. Each time he received an input (a message saying that the state of one of the variables had changed), he was required to rehearse in writing the current state of one of the other variables — or of two of the others, or of all five of the others. Requiring him to rehearse was found to have little or no effect on his ability to keep track of the current states of the six variables.

It seemed odd that rehearsal should not be helpful; perhaps the forced rehearsal of variables whose states had actually been forgotten was disruptive. A second experiment was therefore conducted in which the subject was allowed (but not required) to rehearse, in writing, one of the other variables — or two others, or all five. As before, rehearsal did not have any significant effect.

Although these results are puzzling, they are methodologically convenient: they imply that strenuous attempts to control rehearsal are not necessary.

\*One of the investigators was a National Institutes of Health postdoctoral fellow.

†D. B. Yntema, Human Factors 5, 7 (1963).

### III. MAN-MACHINE COMMUNICATION

Some further theoretical work has been done on the problem of instructing a computer to evaluate multidimensional situations. The basic premise is that if a person could tell a machine how he would evaluate situations, the machine would be able to decide between any two situations more or less as he would himself. The present work has been concerned with the problem of programming the machine to detect types of decisions on which it is likely to make serious mistakes: if the decision falls outside a specified region, the machine refuses to decide and tells the man to do so. An approximate procedure has been developed for estimating how performance is affected by the choice of the critical region. A re-analysis of the data from a previous experiment\* indicates that performance could have been improved by a factor of three at the expense of requiring the man to make about 20 percent of the decisions.

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\* D. B. Yntema and Laura Klem, "Telling a Computer How to Evaluate Alternatives As One Would Evaluate Them Himself," First Congress on the Information System Sciences, Hot Springs, Virginia, 19 November 1962, AD-ESD-TDR 474 Session 4.

## CONTROL RESEARCH GROUP 28

### I. HYBRID COMPUTER SYSTEMS

Programming has progressed on a compiler which will perform automatic mapping and scaling of the digital differential analyzer. The program for the mapping algorithm uses list processing techniques, and methods for performing algebraic operations are being developed.

The digital differential analyzer is nearing completion. All the major operational registers are now complete, and the digital-to-analog converters for the scope displays have been built and operated. The input-output circuitry has been designed and tested, and the final circuits have been ordered. Preliminary designs for connecting the hybrid computer (LINC/DDA) to the new time-sharing system have also been completed.

Studies of applications of the hybrid computer system are continuing. In addition to the applications to trajectory generation and on-line spectral analysis (which have been described in previous quarterly reports), the computation and display of radar system ambiguity functions have been considered. Trial runs have indicated that stereo presentation of functions  $\psi(\omega, \tau)$  for aiding the development of modulating signals is very useful.

### II. ESTIMATION AND CONTROL STUDIES

Studies of waveform design and recursive data processing techniques for nonlinear regression problems are continuing. Results on the recursive estimation of the frequency of a sine wave have been documented.\* Investigations into data processing techniques for a spatial array of sensors with multiple signal sources are also proceeding.

The mathematical theory of stationary occurrence processes is being investigated and exploited to handle a variety of problems associated with sampling continuous time processes. Results have been obtained on a variety of specific problems which include:

- (a) Effects of random sampling,
- (b) Effects of time jitter in periodic sampling,
- (c) Optimum techniques for reconstructing the original processes,
- (d) Relative performance of suboptimum reconstruction techniques.

Further research and documentation of the present results are under way.

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\*L. A. Gardner, Jr., "Computationally Feasible Frequency Estimates in the Presence of Unknown Phase and Amplitude," Technical Note 1965-4, Lincoln Laboratory, M.I.T. (11 March 1965), DDC 613341.

## RADIO PHYSICS DIVISION 3

### INTRODUCTION

This section summarizes the research and development efforts of Division 3 for the period 1 February through 30 April 1965. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semi-annual Technical Summary Report and the Quarterly Letter Report to ARPA.

J. W. Meyer  
Head, Division 3

M. A. Herlin  
Associate Head

# DIVISION 3 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1965

## PUBLISHED REPORTS

### Technical Reports

TR No.				<u>DDC Nos.</u>
372	Measurement of Properties of Spread Channels by the Two-Frequency Method with Application to Radar Astronomy	T. Hagfors	11 January 1965	614233
374	Ionospheric Backscatter Observations at Millstone Hill	J. V. Evans	22 January 1965	*

### Journal Article<sup>†</sup>

JA No.				
2479	The Cause of the Midlatitude Evening Increase in $f_0 F_2$	J. V. Evans	J. Geophys. Res. <u>70</u> , 1175 (1965) (DDC 614310)	

\* \* \* \* \*

## UNPUBLISHED REPORTS

### Journal Articles

JA No.				
2340-3	Radio Wave Propagation Through the Earth's Atmosphere and Ionosphere	T. F. Rogers J. V. Evans		
2340-8	Relations Between Rough Surfaces and Their Scattering Properties as Applied to Radar Astronomy	T. Hagfors		Accepted by <u>Radar Astronomy</u> (McGraw-Hill, New York)
2512	Midlatitude Ionospheric Temperatures on Magnetically Quiet and Disturbed Days	J. V. Evans		Accepted by J. Geophys. Res.
2548	Ionospheric Backscatter Observations at Millstone	J. V. Evans		Accepted by Planet. Space Sci.
2553	A Comparison of Rocket, Satellite, and Radar Determinations of Electron Temperature at Midlatitudes	J. V. Evans		Accepted by J. Geophys. Res.

\* Not yet assigned.

<sup>†</sup> Reprint available.

Division 3

Unpublished Journal Articles (Continued)

JA No.

2568 More on Wet Radomes J. Ruze Accepted by IEEE Trans. Antennas Propag.

2573 Radio Echo Observations of Venus and Mercury at 23 cm Wavelength J. V. Evans  
R. A. Brockelman  
J. C. Henry  
G. M. Hyde  
L. G. Kraft  
W. A. Reid  
W. W. Smith Accepted by Astron. J.

Meeting Speeches\*

MS No.

1244A Radar Studies of the Moon J. V. Evans Colloquium, University of Chicago, 8 April 1965

1324 Ionospheric Backscatter Observations at Millstone Hill J. V. Evans NATO Advanced Study Institute, Finse, Norway, 21-30 April 1965

1355 Radar Studies of the Lunar Surface T. Hagfors Committee 17, International Astronautical Union, Greenbelt, Maryland, 15-16 April 1965

1365 Comments as Moderator of the Session on Passive Microwave Radiometry M. L. Meeks NASA-GCA Workshop on Vertical Radiation Probing, Bedford, Massachusetts, 23-24 April 1965

1368 Some Recent Radar and Radiometric Lunar Studies at Lincoln Laboratory T. Hagfors Seminar, University of California, Berkeley, 30 April 1965

\* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

## SURVEILLANCE TECHNIQUES

### GROUP 31

Group 31 operates and maintains the Millstone radar complex and the Haystack experimental facility at the Laboratory's Millstone Hill Field Station. The Group also conducts a program of radio physics, astronomy, and space surveillance research using these facilities.

During this quarter, activities at Millstone have included continued work in space surveillance techniques, auroral measurements, and initial gathering of data at L-band on the scattering characteristics of the moon. Radiometric observations at Haystack have continued and the first radar observations of Mercury at X-band have been made.

#### I. SPACE SURVEILLANCE

##### A. Observational Program

The Millstone satellite observation program continued on a one-day-a-week schedule during most of this quarter. At Air Force request, Millstone participated in a test involving the entire SPADATS System for purposes of evaluating the System performance and the various sensors. Thirty-one "difficult" satellites of SPADATS interest were observed, many several times. The "grapefruit" satellite, Vanguard I, was observed to a range of 2250 nautical miles.

Four early revolutions of LES 1 (Lincoln Experimental Satellite) were observed for the Space Communications Program. Three objects were observed in this orbit, including the upper stage and truss assembly. The failure of the LES injection rocket to fire was confirmed by these observations.

At DOD request, some 28 separate foreign objects were observed during a special series of operations. The MITRE-Millstone interferometer was activated during certain of these tests.

On 1 April, Millstone gathered data on a Trailblazer II operation from Wallops Island. Re-entry data were obtained on the payload and other stages of the velocity package.

The MITRE-Millstone interferometer system was returned to operation the week of 28 March, after nearly a two-month shutdown while an on-line computer was installed at the MITRE station in Bedford.

##### B. Sensor Improvement Program

Progress on the digital monopulse system has been slower than expected. The interface to the computer is nearing completion and should be ready for checkout in May. Certain subsystems have been physically relocated and diagnostic procedures and CG 24 programs for testing Digimon subsystems have been developed.

The commercial computer installed at Millstone last November has still not achieved operational status. Initiation of software developments in support of the Millstone Hill surveillance program has been held up seriously by the lack of this machine.

## II. RADIO ASTRONOMY

The radiometer box has been installed on the Haystack antenna for approximately two-thirds of the time during this quarter. The work reported below plus training activities have utilized the box an average of 35 hours a week.

### A. Antenna Evaluation

Preliminary data on pointing accuracy, gain, and antenna efficiency were reported in the last quarterly progress report. During this period, data were gathered which permitted a more precise determination of pointing errors, an evaluation of antenna focusing characteristics, and the preparation of antenna patterns at 7.75 and 15.750 Gcps.

The elevation pointing error is presently known to within  $\pm 0.005^\circ$  for elevation angles above  $20^\circ$ . The error is a smooth monotonic function of elevation, has a maximum value of  $0.050^\circ$ , is repeatable from day to day, and is the same when measured with different radio sources. The azimuth error is known to with  $\pm 0.008^\circ$  and is not so well understood.

Pattern measurements were performed with the test transmitter truck located on Pack Monadnock Mountain, about 25 miles from the station. Some results are tabulated below.

Frequency (Gcps)	Measured Beamwidth (deg)	Peak Side-Lobe Levels (db)
7.75	0.069	23
15.75	0.037	20

A report is in preparation which summarizes the measurements of antenna efficiency, noise temperature, pointing errors, patterns, and polarization characteristics.

Positions of many of the radio sources used in the antenna evaluation programs have not previously been measured at these high microwave frequencies. However, by repeated measurements at many different azimuths and elevations, it has been possible to build up a body of data which permits the separation of possible source-position errors from antenna-pointing errors. A basic understanding of the structure of the radio sources used has also been helpful.

In view of the accuracies required and the frequency range concerned, it is considered that the present use of astronomical sources in evaluating the performance of the Haystack antenna is a pioneering effort. the results of which should be of value in precision antenna calibrations of the future.

### B. Observational Program

The extensive program of radio astronomical measurements planned in cooperation with personnel from the Massachusetts Institute of Technology and from Harvard College Observatory has begun. Perhaps a dozen people of professional or advanced graduate-student status have now obtained operating experience and familiarity with the operation of the antenna, the radiometric equipment and the computer pointing program.

An experiment to determine the blackbody disk temperature of Mars (which was at opposition on 12 March) was performed in cooperation with Professor A. E. Lilley and Mr. H. Penfield, both of Harvard University. The goal was to confirm the previous result obtained at 9 Gcps by the Naval Research Laboratory and to look for any possible time variation of the temperature.

A temperature of approximately 200°K was measured, which is in agreement with the previous measurements.

The Mars experiment was an excellent test of the sensitivity of the Haystack radiometric system at 8 Gcps. The increase in antenna temperature attributable to Mars was  $\sim 0.1^{\circ}\text{K}$ ; the received flux density was 1 flux unit ( $10^{-26}$  watt/meter<sup>2</sup>/cps). This signal can be measured with signal-to-noise ratio of 20 with one hour of integration.

The radiometric portion of the projected lunar studies program began with 8-Gcps polarization observations at Haystack on 17 and 20 February. From the degree of polarization measured as a function of angle of incidence, a dielectric constant of 1.8 was deduced for a smooth moon model, while a value of 2.0 was inferred for a moon model of the degree of roughness indicated by past radar results. Thus, the discrepancy between radiometric and radar derived values for the lunar dielectric constant persists ( $\epsilon_{\text{radar}} \approx +2.6$ ).

### III. RADAR ASTRONOMY

#### A. Lunar Studies

New lunar ephemeris programs, based on programs used at Arecibo, were developed for use at Millstone and Haystack.

Nine observations of the moon were made with the Millstone radar at 23 cm, using pulse lengths in the range from 10 to 300  $\mu\text{sec}$ . From these, the L-band power vs range relationship was derived. As expected, the "highlight" so strongly evident at 68 cm is somewhat less pronounced at 23 cm. No reliable total cross-section estimate has as yet been derived.

All work thus far has been done by utilizing circularly polarized transmission. Analysis of signals received in the direct and orthogonal polarizations implied that the lunar disk is uniformly bright when viewed in depolarized radiation.

#### B. Planetary Studies

The first successful X-band radar observations of Mercury were made with the Haystack system during this quarter. Out of 37 attempts, 31 successful runs were obtained in the period 15–23 April. A single run consisted of unmodulated CW transmission for approximately 10 minutes (more than the round trip time), reception of signal-plus-noise for 10 minutes, and reception of noise only for 10 minutes. The received signal was passed through a filter, of width 250 cps, centered on the predicted frequency of reception and was then analyzed in real time on the Univac 490. In the analysis, the 250-cps band was divided into nine 25-cps filters. The spectra thus derived for the noise-only periods were subtracted from those derived from the signal-plus-noise periods to yield spectra of the signal alone.

A weighted average was derived for the 31 successful runs, which yielded a peak approximately five standard deviations in magnitude. The spectral width to half-power width was on the order of 65 cps. The mean frequency appeared below the predicted by about 10 cps. Parameters for the experiment were as follows:

CW power	25 kw
Frequency	7.750 Gcps
Receiver noise temperature	145°K $\pm$ 10 percent
Antenna gain	66.1 db
Effective aperture	$\sim 460 \text{ m}^2$ (efficiency $\sim 46$ percent)

The best estimate of the reflectivity of the planet based on the results of these measurements is 5 percent. The results of the experiment appear valid to less than  $\pm 3$  db.

#### IV. IONOSPHERIC STUDIES

##### A. Observations

In the radar program of observing backscatter from the ionosphere, there were four 48-hour continuous runs at 440 Mcps and two 12-hour runs at 1295 Mcps. Observations at 440 Mcps were also made during a 2-hour period which included a pass over by the Alouette satellite containing a top-side sounder. The Alouette-related observations were part of a cooperative experiment with Dr. P. R. Arendt of the U. S. Army Electronics Laboratories.

##### B. Data Reduction and Analysis

Preliminary reduction of electron density profile data has been completed through February 1965. These profiles need to be corrected for the effects of height variations in electron temperature on the backscatter cross section. These corrections are obtained from frequency power spectra of the signals. Analysis of the spectra has been completed through September 1964.

#### V. STATION EQUIPMENT

##### A. Haystack

Integration and upgrading of all subsystems continued. Problems in the functioning of the microwave protection equipment were discovered and some rework of the arc detectors and high-standing wave detectors was required. A total of four Varian Associates VA-849, 25-kw klystrons failed during this period. Two klystrons had output waveguide window fractures; one tube had a punctured filament header; the cause of vacuum failure in a fourth tube has not been ascertained.

The parametric amplifier has been successfully operated with 145°K system temperature in a liquid nitrogen bath as described in Sec. III-B. The cooled waveguide must be repumped after seven days of cooled operation. A variation in the parametric amplifier gain is noted as a function of elevation angle.

Technical proposals for a new 500-kw transmitter were received and a vendor is being selected. Final tests of the Series Beam Switch and Regulator (SBSR) were completed by Energy Systems, Inc. The SBSR, which is being loaned by RADC, will be installed at Haystack during the next quarter. Initially, a VA-849 klystron will be operated at a peak power output of 50 kw.

Design of a CW monopulse tracker was started. This unit will be used for closed-loop control of the antenna pointing and the Doppler steering during operations with X-band active satellites.

A ferrite switch was installed in the receiver waveguide of the R/C box to provide the modulation required for radiometric operation. The signals were processed using the Haystack radiometer terminal equipment and the parametric amplifier and first IF chain of the R/C box. This system was used for radiometric boresight calibration of the R/C box.

Antenna measurements and evaluation are described in Sec. II-A.

### B. Millstone

The antenna slip rings which failed catastrophically in November have been repaired and reinstalled with inspection windows, and improved wiring arrangements. Tower heaters have been installed to reduce dampness and temperature extremes.

The counter-torque anti-backlash drive system has undergone preliminary testing in actual driving of the elevation axis of the antenna.

A new synchro data take-off has been installed on the azimuth axis and indicates errors one-half those of the older unit.

Septated horns have been installed and initial gain measurements show 0.9-db gain in one polarization, 0.6 db in the other. Part of this difference may be loss in the high-power direct-line duplexer which also was installed and operated this quarter. The nulls in the error patterns are still excellent ( $\approx 38$  db) and the side lobes from spillover at the subreflector are improved from  $-32$  to  $-38$  db, approximately.

A multiplexing system for sequencing several quadrature detector outputs into a single A/D converter, plus formatting equipment for interfacing with digital magnetic tape units has been installed and tested. It will be used in the lunar astronomy program.

A boresight and calibration tower with a 6-foot dish and rotatable dipole feed has been erected on a level with the Millstone tracking feed at a distance of 1500 feet. The tower's use in the precise adjustment of radar polarization will be important in the moon work.

## VI. PROPAGATION STUDIES

### A. X-Band Propagation Studies

On 2 April 1965, some preliminary X-band atmospheric scattering experiments were conducted over a 240-mile path, utilizing the West Ford terminal operated by Group 62, and a similar facility located near Fort Dix, New Jersey, operated by and in collaboration with the Army Satellite Agency. A number of samples of data were taken using the narrow ( $0.12^\circ$ ) beams in a variety of angular configurations in azimuth and elevation to explore the angular scattering properties of the atmosphere at these short wavelengths which are important in assessing the interference range of high-powered and highly-directive X-band space communications terminals. Preliminary analysis of the data indicates highly-directive propagation aligned on the great-circle bearings in the absence of rain. The experimental results also indicated some discrepancies in the original bearing computations which have been computed by more precise methods. It is planned to repeat some similar experiments with the collaboration of the ASA group on a noninterference schedule and when the West Ford terminal is not engaged in the satellite communications activities.

### B. Atmospheric Backscatter

Further analysis has continued on the multiwave radar backscatter data obtained at Wallops Island, Virginia, in November 1964 in collaboration with the weather-radar research group of the Air Force Cambridge Research Laboratories (AFCRL). A joint paper, "Multi-wave Back-Scatter from the Clear Atmosphere" by D. Atlas\*, K. R. Hardy\*, K. M. Glover\*, and J. H. Chisholm† was presented by AFCRL at the Spring URSI meeting, 20-24 April, in Washington, D. C.

### C. Solar Coronal Studies

Some further studies have continued on coronal models of electron density and possible influence of enhancements expected during the forthcoming increase in solar activity. These studies included a survey of the possible influence of active solar phenomena on the proposed experiments on relativity with the Haystack facility and possible pertinent radiometric studies of the sun with the Haystack facility.

### D. Auroral Backscatter at L-Band

Several measurements have been obtained at Millstone by Group 31 on backscatter from aurora. These data are being analyzed in conjunction with previous UHF studies conducted several years ago at Round Hill for a comparative assessment of frequency dependence and associated geometry of the angular scattering properties relative to the earth's magnetic field. It is believed that the L-band results may be particularly valuable in assessing the validity of some current theoretical models which have been suggested as a basis for estimating the possible occurrence of auroral effects for future higher-power radar systems operating in the upper UHF and SHF bands.

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\* AFCRL.

† Lincoln Laboratory.

## RADAR DIVISION 4

### INTRODUCTION

This report summarizes the General Research activities of Division 4 during the period 1 February through 30 April 1965. The General Research activities in Division 4 involve Groups 42 and 46 on Haystack Instrumentation, Group 44 on Phased Arrays, and Group 45 on Millimeter Waves. The activities of the Division for Project PRESS, Radar Discrimination, the BMRS Program, Space Communications, and Project Apollo are described in separate reports.

J. Freedman  
Head, Division 4

H. G. Weiss  
Associate Head

## DIVISION 4 REPORTS ON GENERAL RESEARCH

15 December 1964 through 15 May 1965

### PUBLISHED REPORTS

#### Technical Note

TN No.				DDC and Hayden No.
1965-7	Measurements on an L-Band Power Amplifier for Phased Arrays	L. Cartledge	17 March 1965	DDC 614426 H-641

#### Journal Articles\*

JA No.				
2428	Circulator Synthesis	J. A. Weiss	IEEE Trans. Microwave Theory Tech. <u>MTT-13</u> , 38 (1965)	
2488	Ultrasonics	J. J. G. McCue	Science 147, 309 (1965) (DDC 613828)	
2494	The Haystack Microwave Research Facility	H. G. Weiss	IEEE Spectrum <u>2</u> , No. 2, 50 (1965)	
2498	High Efficiency Varactor Upper-Sideband Upconverter	H. J. Pratt W. J. Ince R. C. Sicotte	Proc. IEEE (Correspondence) <u>53</u> , 305 (1965)	

\* \* \* \* \*

### UNPUBLISHED REPORTS

#### Journal Articles

JA No.			
2493	On Surface Wave Coupling Between Elements of Large Arrays	J. L. Allen	Accepted by IEEE Trans. Antennas Propag.
2549	Correlation of Experimental and Theoretical Active Impedances of a Dipole in an Array	B. L. Diamond T. B. Lewis	Accepted by IEEE Trans. Antennas Propag.
2564	Phased Arrays - There is a Future	J. L. Allen	Accepted by Microwave J.

\* Reprints available.

Unpublished Reports (Continued)Meeting Speeches\*

## MS No.

939B	The Care and Feeding of Phased Arrays	J. L. Allen	IEEE, Antennas and Propagation Group, Dallas, Texas, 24 February 1965
1193	Design and Construction of a Multimode Circularly Polarized Monopulse Tracking Feed for High Power Application in a Cassegrain Reflector System	K. J. Keeping	IEEE International Convention, New York, 20-25 March 1965
1252	Introduction to Array Systems	J. L. Allen	IEEE, Spring Lecture Series, Long Island, New York, 11 February 1965
1256	The Haystack Microwave Research Facility	H. G. Weiss	IEEE, Military Electronics Group, Los Angeles, California 3-5 February 1965
1316	Trends in Phased Arrays	J. L. Allen	IEEE, Microwave Theory and Techniques Symposium, Orlando, Florida, 4-6 May 1965
1319	Phased Arrays – There Is a Future	J. L. Allen	Microwave Journal Seminar, New York, 21 March 1965
1152A	Status of Diode and Ferrite Phasers for Array Radars	D. H. Temme	Engineering Seminar, Sylvania Defense Division, Waltham, Massachusetts, 15 April 1965

\* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

# RADAR SIGNAL PROCESSING

## GROUP 42

### I. INTRODUCTION

Group 42 presently is engaged in supporting four Laboratory projects: PRESS, Radar Discrimination Technology, Apollo, and Haystack.

The PRESS and Radar Discrimination Technology activities are described in Semiannual Technical Summary Reports to ARPA and the activities on Apollo are recorded in bimonthly progress reports to NASA. A description of the work on Haystack Instrumentation is given here.

### II. HAYSTACK INSTRUMENTATION

All the Haystack equipment for which Group 42 has been responsible has been completed and is now operating on site. The list of equipment includes: (a) sequential Doppler processor, (b) monopulse angle estimator, (c) test signal generator and target simulator, (d) antenna position digital control subsystem, (e) digital range tracker, (f) real-time clock, and (g) computer interface buffers for angle, range, Doppler, and time.

The remaining work comprises: site-personnel technical indoctrination, testing of the interfaces between the monopulse estimator and the remainder of the angle-tracking equipment, and investigation of the cause of some apparent degradation of the dynamic range capability of the IF delay channel in the monopulse estimator.

## ARRAY RADARS GROUP 44

As part of a continuing program to understand the fundamental limitations and capabilities of array radars, theoretical and experimental investigations are being carried out in Group 44.

### I. S-BAND TEST FACILITY

The modifications to the power supply and modulator for the high-power S-band source are complete. The power supply and modulator have been tested at high voltage. Initial turn-on of the tube has been scheduled for early in the next reporting period.

### II. S-BAND SUBARRAY

#### A. Phasers

Helical ferrite phasers have been built and low-power tested. They have good match (VSWR < 1.3) and phase track to within 4° across the band. They will be high-power tested as soon as the high-power source is operational.

#### B. Phaser Drivers

Development of a solid state driver for the ferrite phase shifters to be used in the S-band subarray has been under way. A flux transfer driver with intermediate cores was developed and performed satisfactorily over a wide range of phase-shifter temperatures. Development of a transistorized driver that controls the volt-time integral with semiconductor electronics has shown much promise and is being continued.

RF connector assemblies for use in the subarray have been designed and are being tested. A four-element linear assembly of coaxial "push" connectors suitable for array use at S-band has been tested. A sixteen-element assembly is being constructed. These connector assemblies are intended for use at the "blind" end of long subarray electronic packages.

### III. HIGH-POWER PHASERS

#### A. Some X-Band Phaser Remedies

We have observed in high-power phaser programs elsewhere troubles with spurious reflections, high-power loss, and reproducibility. We have conducted laboratory tests at X-band to verify the following: (1) Peak-power effects can readily be avoided by selecting a ferrite with a saturation magnetization which satisfies the relationship  $4\pi\gamma M_s/\omega < 1/2$ ; (2) magnetostriiction effects can cause large changes in phase, but these effects can be minimized if magnesium-manganese ferrites are used, or if the mechanical stress is held constant and low; (3) spurious reflections and hot spots are suppressed if a spring-loaded ferrite mount is used, and if the contacting surfaces are ground flat to 0.2 mil per foot and polished to an 8-micron finish.

### B. Composite Loop Phaser

A ferrite composite loop remanent waveguide phaser has been built and tested. The phaser configuration consists of two ferrite slabs located in the circularly polarized RF magnetic field regions of the guide. The magnetic circuit is closed external to the guide to form a toroid structure that has an equivalent air gap (the metallic waveguide wall is a thin foil). The composite loop phaser has an excellent temperature stability. The experimental X-band unit only has a differential phase change of 6° and an insertion phase change of 3° from 20° to 140°C.

## IV. MUTUAL COUPLING

### A. Analytical Studies

Programs for the computation of the mutual coupling effects between circularly polarized crossed-dipole elements in planar arrays have been completed. Computations have been performed to obtain the gain function, impedance, and polarization variation of the center crossed-dipole pair as a function of scan angle. The computer programs can make this computation for planar arrays as large as  $13 \times 13$  elements. In conjunction with this work, an investigation into the programming modifications necessary for determining edge-element effects has been initiated.

An investigation of the effects of mutual coupling on arrays using reactive power dividers and either reciprocal or nonreciprocal lossless phasers has been completed and a report on the results is in preparation. Programs were written to compute the aperture illuminations and patterns of both linear and planar arrays of dipoles driven by reactive divider corporate-feed networks.

The program for computing the solutions of equations for the open waveguide planar array is still under way. A fundamental error in the original derivation was discovered and corrected.

### B. Experimental Program

The 900-Mcps linear array has been dismantled and a platform has been constructed on the pedestal to use for taking gain function patterns and mutual impedance measurements in the radome. A support to hold the dipole, waveguide, and log-periodic arrays is being constructed to facilitate pattern recording.

## V. SOLID STATE TRANSMITTERS FOR VHF AND UHF ARRAYS

Some time and effort have been devoted to outlining a program aimed at developing solid state transmitter elements for use in practical phased array radars. The first portion of the program, an attempt to survey the state of the art and define problem areas, is under way. Theoretical and experimental investigations of the factors limiting pulse ratings of VHF and UHF power transistors are planned for the next reporting period.

## RANGE MEASUREMENTS GROUP 45

### I. INTRODUCTION

The principal activities of Group 45 are under the Program in Radar Discrimination Technology (RDT) and are reported in the Semiannual Technical Summary Reports to ARPA on the RDT Program.

### II. MILLIMETER-WAVELENGTH SYSTEMS

The millimeter-wavelength systems project affords the opportunity for: (a) experimental equipment development, (b) study of millimeter-wavelength space communications, and (c) research in radar and radio astronomy. The project now consists principally of tasks in radiometry and radio astronomy.

The modifications to the mount were completed early in the reporting period, and the antenna was in full operation virtually throughout the period. Controls for the new mount-drive motors, however, have been of a temporary nature, and the final rate-servo control system is only now being constructed.

Conversion of the equipment to receive two polarizations on the 8-mm radiometer in the 28-foot antenna has started. The ferrite polarization switch has been received and checked out. A special directional coupler for calibration purposes has been designed. A modulator for the polarization switch is still needed, as is another synchronous detector. This modification is expected to be completed within the next reporting period, and a lunar study will then be undertaken.

Activity in preparation for further lunar radar experiments has continued and is reported with the activities of Group 46.

The pointing accuracy of the antenna and the integrity of the antenna gain have been clarified greatly by the work of the present reporting period. The pointing inaccuracies of the antenna have been reduced by measuring optically the pointing errors along a declination circle. For this method to succeed, the errors must be consistent from day to day and must be dependent only upon the pointing direction of the antenna. The known systematic errors are taken into account in antenna pointing and data reduction.

Considerable effort was made in measuring the pointing errors in the region of the sky traversed by the radio source in Taurus, i.e., the declination circle 22°N. Actual radiometric measurements of the source were undertaken, and these imply pointing accuracies of 0.7 min-arc rms or less.

During the period of this report, reliable measurements of the antenna gain were made. The results of these measurements refute the conclusions reported in the last quarterly progress report and indicate a gain of 66.8 db/isotropic at 35 Gcps, which is about the same as measured one year ago. This value of gain corresponds to an effective area of  $28 \text{ (m}^2\text{)}$  or an aperture efficiency of  $49 \pm 5$  percent.

During the reporting period, the following sources were observed: the Moon, Taurus A, Cassiopeia A, Cygnus A, and 3C84 (NGC 1275). The details of the observations and their results are discussed in other reports.

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Currently, an effort is being made to determine sky-brightness distributions from antenna-temperature distributions. This determination is desirable, because the antenna acts as a filter in receiving the energy, thus distorting the sky distribution. A complete knowledge of the antenna pattern permits such restoration within that range of spatial frequencies which the antenna can resolve.

## MICROWAVE COMPONENTS GROUP 46

### I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave requirements arising from radar projects. Contributions are made to the General Research Program through the support of Haystack Hill, operation of a high-power microwave laboratory, development of low-noise receiver techniques and receivers for space communications, and studies of very-high-gain antennas and antenna feeds.

### II. HAYSTACK HILL MICROWAVE COMPONENTS

#### A. 7750-Mcps Transmitter

The transmitter was completed and tested during the early part of the reporting period. An RF output of 80-kw CW was demonstrated. The output was limited to that level by the connections to the power supply. During a succeeding run, the VA-879, 100-kw klystron suffered a cracked window for an undetermined reason. Since only one VA-879 was available at the time, the klystron cabinet was converted for operation with a VA-849, 25-kw klystron. A second VA-879 is now on hand, and a second klystron cabinet is being fabricated.

Operation of the system has revealed some tube and equipment problems. Three faults have been experienced with Varian VA-617C TWTs to date. One tube failed when an external arc track developed across an insulator. The tube was returned to Varian and repaired by suitable cleaning and potting techniques. A thermally warped electron gun in a second TWT caused an excessive helix current. This fault resulted from the design of the early electron guns and has been avoided in later tubes. The third fault developed in the tube that had been repaired by Varian. This tube now exhibits an excessive helix current, probably the result of the electron-gun design. A fully potted version of the VA-617C with an improved gun design is currently operating in the transmitter and has thus far exhibited no problems.

The arc detectors at Haystack have exhibited a transient sensitivity well above a level that can be tolerated. The problem was eliminated by installing transient-suppression capacitors in the arc detectors and on the power lines which feed the power supplies. The mechanical design of the arc detector has room for improvement, and the protection of the detector from the large thermal gradients in the klystron cabinet is inadequate. A mechanical redesign of the arc detector is under way to permit the removal of the electronics circuitry from the waveguide without breaking the high-power waveguide run, and to eliminate the other problems.

In view of klystron removal problems associated with the present design and the desire to change the klystron without removing the cabinet, a klystron cabinet of improved design is under construction. The power sampling and monitoring waveguide components have been redesigned as a compact assembly to permit the easy interchange of 25- and 100-kw klystrons.

Development has started on a VSWR sensor system which is capable of operation in both pulse and CW modes. A new, compact termination has been developed for the remote introduction of an adjustable mismatch into the waveguide system. The mismatch unit simulates a high VSWR for checking the VSWR sensor operation.

### B. Noise-Rejection Filter

Construction of the six-cavity-pair 8350-Mcps noise-reject filter has been completed. Low-power tests show it to have a rejection of greater than 80 db over a 43-Mcps band centered at about 8350 Mcps. It has a VSWR of less than 1.06 over the passband from 7740 to 7760 Mcps. Measurements of the pass-band attenuation and the high-power breakdown level have not yet been made.

### C. Low-Noise Receivers

During this reporting period, all the low-noise receiver equipment was checked out at the site. One parametric amplifier cascade has consistently operated satisfactorily at room temperature. The cascade has also operated satisfactorily at 77.4°K, except that its sustained operation in liquid nitrogen is limited to a period of from 10 days to 2 weeks. After an immersion of that interval, enough liquid nitrogen seeps into the parametric amplifiers to make them inoperative. The second parametric amplifier cascade was returned to the Laboratory and modified for use with Sylvania varactor diodes. It was found that this unit would not operate at both 77.4° and 300°K without retuning. The cascade was aligned for operation at 77.4°K and returned to the site.

During initial operations at the site, the receiver gain was observed to vary about 2 db as the antenna was elevated. The trouble stemmed in part from the fact that the pump waveguide was inadequately fastened, and in part from some microphonic relay contacts in the paramplifier pump power regulator. Measures were taken to properly secure the pump waveguide. In a later test with a receiver gain of approximately 20 db and the regulator disconnected, the antenna was elevated from the horizon to the zenith. During this test, the receiver gain varied 0.4 db. The employment of the radar at the time did not permit the test to be repeated with the pump regulator in operation.

An additional problem arose in connection with pickup in the pump regulator circuit. This pickup was amplified and appeared as a modulation on the pump input to the parametric amplifiers. Part of the pickup was introduced by some auxiliary control and monitor leads. The most troublesome portion was introduced with the input from the power monitoring diode. Temporary measures have materially reduced the pickup. The regulator circuitry will be reworked and additional filtering added in an effort to eliminate the problem.

Since operation of parametric amplifiers in cryogenic dewars is planned until the fall, plans have been made to adapt the new electroformed paramplifiers for liquid cooling. A gas-tight can, which will accommodate two amplifiers, has been designed, and low-temperature seals have been investigated. Both teflon-coated stainless steel O-rings and indiumO-rings

have proved satisfactory in tests. All the necessary parts have been obtained for the fabrication of six can assemblies. The first assembly is under construction.

### III. SOLID-STATE AMPLIFIERS

#### A. Cooled, Varactor-Diode Amplifiers

All the required hardware has been procured for the assembly of thirty L-band varactor-diode parametric amplifiers. The Joule-Thomson expansion refrigerator is undergoing acceptance tests at the Air Products and Chemicals, Incorporated, plant in Allentown, Pennsylvania. Several complete amplifier-and-heat-exchanger units have been evacuated to a vacuum of  $10^{-5}$  torr and tipped off. Each unit is equipped with a cryosorption getter to adsorb the products of outgassing. Installation of the cryogenic equipment and amplifiers is anticipated for May at the White Sands Missile Range.

#### B. Transient Response of L-Band Parametric Amplifiers to RF Leakage Pulses

A study has commenced of the transient changes in gain and phase experienced by an L-band parametric amplifier in response to RF pulses comparable with those usually present in radar receiver lines as a result of transmitter leakage. Pulse lengths of from 2 to 2000  $\mu$ sec and power levels of up to 10 watts peak have been employed in the study. The transient response of the amplifier depends upon its gain and the circuit Q's. For an amplifier gain of 15 db, a 10- $\mu$ sec, 200-mw pulse gave rise to a 0.3-db gain variation and a 3° phase shift. A 0.1-db gain variation was experienced at leakage power levels as low as 2 mw peak.

During tests, the parametric amplifier was located in one arm of a microwave bridge and operated as an amplifier with a CW input. The output of the bridge was detected and displayed on an oscilloscope. With the bridge initially balanced, an appropriate RF pulse was applied to the amplifier input, and the bridge output was monitored as a function of time following the termination of the pulse. The output of the bridge was found to decay as the inverse square root of time following the pulse rather than exponentially with time. Half-amplitude decay times of 50  $\mu$ sec were typically encountered. By appropriate adjustment of the diode bias, a near-balance of the bridge could be obtained at any instant of time in the interval following the termination of the pulse. This result suggests that the main effect of the transient was one of an effective change in the diode capacitance. For the higher-power RF pulses, the change in capacitance can be explained on the basis of diode heating. However, the heating mechanism will not account for the change in capacitance associated with low-power RF pulses.

The above tests were conducted at room temperature. It is expected that the effect of RF leakage will be even greater when the parametric amplifier is operated at cryogenic temperatures. Measurements of the transient response of the amplifier will be made at these temperatures.

#### C. Diode Measurements

An evaluation at cryogenic temperatures has been made of a number of experimental GaAs varactor diodes which were supplied by Sylvania Electric Products, Incorporated. The varactors were of both the epitaxial and the nonepitaxial varieties. The substrates consisted of degenerate

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GaAs which was doped with either selenium, tellurium, or tin. The diodes were fabricated with various dopant concentrations, epitaxial layer thicknesses, and diffusion depths in an effort to find a diode design which suffered a minimum degradation in quality with a reduction in temperature.

Suitable definitions of the elements in the equivalent circuit of a packaged diode have been shown to yield a lumped-element circuit with an impedance at its terminals which is the same as the total radial-line impedance of the packaged diode, with the outer surface of the diode taken as the terminal surface. Consideration of the packaged diode as a radial-line structure permits an analytical justification for the incorporation of the diode circuit with the circuits of waveguide, coaxial-line and strip-line diode mounts. As a result, the lumped-element equivalent circuit of a packaged diode has been directly related to the microwave-equivalent circuit of the diode and the mount together. Diode-element values, which were obtained from low-frequency measurements, have been used in conjunction with the theoretically determined circuits of mounted diodes to predict resonant frequencies at X-band of diodes in waveguide, coaxial-line and strip-line mounts. Similarly, antiresonant frequencies of greater than 20 Gcps were predicted for diodes in a radial cavity. The validity of all these predictions was verified by measurement. A report, which describes the work, is now in preparation.

#### IV. 8-mm RADAR TRANSMITTER

During this reporting period, a program was formulated for the construction of an 8-mm CW radar transmitter. The transmitter will have an initial output capability of 400 watts, with an output capability of 1000 watts in its final configuration. The transmitter will consist of a phase-locked, 10-watt Elliott klystron followed by a TWT amplifier. A Watkins-Johnson TWT, which was developed for Lincoln Laboratory, will be used in the first phase of the program. The TWT is capable of an average output of 1000 watts with a saturated gain of 13 db.

Since power sources of the order of several hundred watts have not heretofore been available, there is considerable doubt as to whether commercial waveguide components can handle such amounts of power. Consequently, a traveling-wave resonator will be constructed to determine the power-handling capability of 8-mm waveguide components.

The necessary equipment and components for this project have been ordered and will be delivered during the next few months. It will then be possible to assemble the resonant ring and start the power tests.

## ENGINEERING DIVISION 7

### INTRODUCTION

Engineering services to the Laboratory's General Research program in the quarterly period ending 30 April have consisted principally in the design of devices used in high pressure research, the upgrading of radar research facilities at both Millstone and Haystack Hill, and the continuing development of computer-aided analysis techniques for antennas and their supporting structures. These activities are reported briefly in the following paragraphs.

J. F. Hutzenlaub  
Division Head

## ENGINEERING DIVISION 7

### I. HIGH-PRESSURE RESEARCH

#### A. X-Ray Camera

A high-pressure apparatus has been designed for use in conjunction with an x-ray camera to investigate polymorphic transitions of materials under pressure — in particular, those with extremely low shear properties.

The system is designed around a cubical pressure chamber, on four sides of which are anvils restrained by means of multiple rings to form a die. The die is mounted in a housing which rides on the press columns. The housing also serves to cool the experiment.

The two remaining anvils are actuated by a small 50-ton double-acting press. X-rays are collimated through a 0.015-inch hole in one of the anvils, and the diffracted beam is then projected onto a film which is mounted on the opposite anvil.

Other features of the apparatus are the capability to heat the specimen, by means of internal resistance heating, and to transform the device into an X-ray high-pressure unit to be mounted on the goniometer.

#### B. Liquid Helium Probe

A tool has been designed to measure the Hall effect of materials at low temperatures.

Maintaining specimen contacts at temperatures as low as 4°K was solved by utilizing tungsten needles which are independently actuated by a lever mechanism which, in turn, obtains its constant tension from springs mounted outside the cold region.

#### C. Low-Pressure Optical Absorption Cell

This device was developed to provide a tool for the observation of chemical and physical phenomena at pressures up to 5000 psi by optical methods.

The application of four windows gives the investigator the choice of two optical path lengths: 5 and 3 cm.

#### D. Hydrostatic Pressure Apparatus

Hydraulic pressure up to 600,000 psi is developed in a 6-inch-long by 1-inch-diameter chamber consisting of multiple restraining rings around a carbide liner.

Because of its low magnetic permeability, tungsten-carbide material is used to reduce the distortion of the magnetic field. This feature enables the researcher to investigate the effect of pressure on the Hall measurement of materials.

True pressure values are obtained by means of an internally mounted Manganin cell and does not depend on the load-over-area ratio.

## II. MILLSTONE HILL L-BAND ANTENNA SYSTEM

The 12-horn monopulse feed assembly has been modified by the replacement of the original horn sections with 12 new, crossed Septum horns. Also, a new Rexolite feed-horn radome assembly which includes an inflatable-fabric, hemispherical weather dome has been installed.

The high-power azimuth rotary joint and waveguide transmission line to the 12-horn monopulse feed assembly have been changed from WR-650 to WR-770 waveguide components.

The repaired high-power slip-ring assembly has been re-installed. Design modifications consisting of inspection windows and ring shrouds were added to the assembly.

## III. CONSTRUCTION OF A POLARIZATION MONITOR TOWER AT MILLSTONE

This installation consists of a 150-foot Stainless, Inc., G4 tower with ladder, belt, safety rail, and work platform at the 140-foot level. Grounding and obstruction lights are installed. The tower is located approximately 1600 feet southwesterly from the Millstone radar site.

A 6-foot diameter reflector and feed assembly are mounted at the 146-foot level. A manual device at the base of the tower permits turning the reflector 120°.

## IV. STRUCTURES RESEARCH

Work has continued on paraboloidal shell analysis and on the improvement and development of computer programs for the analysis of frames structures.

### A. Paraboloidal Shell Analysis

The following additions to the paraboloidal shell analysis programs have been completed:

- (1) Determination of deflections in a symmetrically and/or antisymmetrically loaded paraboloidal shell with an interior support.
- (2) Automatic calculation of the surface phase error caused by the calculated distortions.
- (3) Extension of the honeycomb sandwich shell programs.

The user's manual covering the membrane shell analysis should be published during the early part of the coming quarter. Emphasis next quarter will be on extending this user's manual to the remaining groups of programs and to the conversion of all these programs from Fortran II to Fortran IV language. This change is required by present and future trends in source program languages.

### B. Framed Structures Analysis

The modifications to the STA1R program are nearing completion and are being tested. This work should be completed during the coming quarter.

The expansion of the dynamic analysis program is also nearly complete, with only a final testing of the interrupt-restart option to be done. A report covering the use of this program is in preparation.

## V. HAYSTACK

### A. Mechanical Engineering

#### 1. RF Box

A portable hoist and transport dolly to facilitate handling of the high-power klystron to and from its socket in the equipment rack within the RF box are being designed.

#### 2. Thermal Investigation

Instrumentation has been installed as the first phase of an investigation to determine air temperature gradients within the radome and their effect on reflector surface accuracy. All instrumentation and temperature probes are being checked out for continuity, calibration, and over-all system accuracy.

#### 3. Antenna Modification

Modifications to the antenna assembly which have been completed in this quarter include the addition of a safety gate at the open end of the RF raceway structure and the high-voltage cable termination at the RF box station.

Preliminary studies are under way for installing a 500-pound capacity auxiliary hoist system to lift equipment up to the RF raceway.

#### 4. Distilled Water Pipe Line System

The hoses and hose supporting structure in the azimuth wrap were modified to allow full azimuth rotation without excess strain on the hoses and rotary joints and to eliminate chafing of the hose on the azimuth encoder support.

Two motorized ball valves were installed in the 4-inch water lines (one in the supply and one in the return) at the base of the antenna tower. These are safety valves which automatically shut off the water in the event of a water pipe failure in the RF equipment box. A moisture sensor has been installed in the RF equipment box which will activate these valves.

The teflon seals in the water line rotary joints were found to be unsatisfactory and were replaced by a "Buna N" rubber type.

A major effort has begun on a complete redesign of the water manifold in the RF equipment box. This will include relocation as well as the use of flow limiters, flow meters, temperature and pressure sensors, ball valves, and flexible lead-in lines.

#### 5. Strain-Gage Program

Instrumentation for monitoring the Haystack radome beam strains has been installed and is now being tested and calibrated by Group 73.

#### 6. Cooling for Low-Noise Amplifiers

Experiments are being conducted to seal out the liquid nitrogen from the Texas Instrument Co. Parametric Amplifiers by using 1- and 3-mil mylar bags. This is in connection with the batch-filled dewar systems.

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The closed-cycle refrigerators have undergone extensive life tests and are to be used with new parametric amplifiers for the Haystack receivers as a replacement for the batch-filled dewars.

### 7. Calibration of Optical Probe

The K&E optical probe was calibrated in a temperature-controlled chamber. Errors of up to 43 seconds of arc were found. Procurement of a special Kern DKM-3 theodolite has been initiated to enable measurements to be made on the reflector in the near future. The K&E is under study to determine the feasibility and advisability of having it reworked for future use.

### 8. North American Aviation Activity (Antenna System)

In response to five unsolicited proposals submitted by North American Aviation, Inc., to Lincoln Laboratory, NAA has been requested to prepare work statements and budgetary requirements for studies which include: re-rigging of the reflector surface, access provisions throughout the reflector backup structure, and a stress analysis of the RF raceway support structure as a function of increased RF box weight.

## B. Construction Engineering

### 1. Switchgear Room

A ventilation and cooling system utilizing outside air was designed and installed to serve the three motor generators installed in the switchgear room.

The work included installation of a ventilation unit on the roof with a capacity of 12,000 cfm, ductwork, outlets, controls, equipment shelter for the unit, installation of new doors, miscellaneous masonry work, relocation of existing conduit and wiring and installation of additional lighting, switches, breakers, wire conduit, and wireways.

### 2. Radome Heating System

The radome heating system consisting of 30 heating units and two 125-hp hot water boilers with a capacity of 8,000,000 Btu/hr was completed, checked out, and placed in proper operation.

## SOLID STATE DIVISION 8

### INTRODUCTION

This abbreviated report covers the work of Division 8 from 1 January through 30 April 1965. A more detailed presentation is covered by the Solid State Research Report for the same period.

H. C. Gatos

Head, Division 8

A. L. McWhorter

Associate Head

P. E. Tannenwald

Assistant Head

## DIVISION 8 REPORTS ON GENERAL RESEARCH

15 January through 15 May 1965

### PUBLISHED REPORTS

#### Journal Articles\*

##### JA No.

2379	The Dark Side of the Laser	J. J. Schlickman R. H. Kingston	Electronics <u>38</u> , No. 8, 93 (1965)
2390	Electrochemical Dember Effect in Semiconductors	W. W. Harvey <sup>†</sup> M. C. Finn	Surface Sci. <u>2</u> , 456 (1965) (DDC 614180)
2392	Single Crystal Growth of Transition Metal Oxides from Poly-tungstate Fluxes	W. Kunmann <sup>†</sup> A. Ferretti R. J. Arnott D. B. Rogers	J. Phys. Chem. Solids <u>26</u> , 311 (1965)
2394	Band Gap of Boron Phosphide	R. I. Stearns <sup>†</sup>	J. Appl. Phys. <u>36</u> , 330 (1965)
2412	Peritectic Reaction in the Superconductor Nb <sub>3</sub> Sn (Cb <sub>3</sub> Sn)	F. J. Bachner H. C. Gatos M. D. Banus	Trans. Met. Soc. AIME <u>233</u> , 277 (1965) (DDC 613812)
2418	Semiconductor Injection Laser	R. H. Rediker	<u>McGraw-Hill Yearbook of Science and Technology</u> (1965)
2429A	Generation of Stokes and Anti-Stokes Radiation in Raman Media	H. A. Haus <sup>†</sup> P. L. Kelley H. J. Zeiger	Phys. Rev. <u>138</u> , A960 (1965)
2443	Electric Furnace for Operation in Oxidizing, Neutral, and Reducing Atmospheres to 2400°C	T. B. Reed R. E. Fahey	Rev. Sci. Instr. <u>36</u> , 289 (1965)
2446	Electromagnetic Mode Mixing in Nonlinear Media	R. H. Kingston A. L. McWhorter	Proc. IEEE <u>53</u> , 4 (1965) (DDC 613890)
2447	Superconducting Characteristics of the High-Pressure InSb- $\beta$ Tin System	M. D. Banus S. N. Vernon H. C. Gatos	J. Appl. Phys. <u>36</u> , 864 (1965)
2452	Elastic Constants of HgTe	J. C. Mavroides D. F. Kolesar	Solid State Commun. <u>2</u> , 363 (1964) (DDC 614308)
2456	Pressure Dependence of the Alpha-Beta Transition Temperature in Silver Selenide	M. D. Banus	Science <u>147</u> , 732 (1965) (DDC 613891)

\* Reprints available.

† Author not at Lincoln Laboratory.

## Division 8

Published Journal Articles (Continued)

## JA No.

2457	Magnetic Properties of InAs Diode Electroluminescence	F. L. Galeener* I. Melngailis G.B. Wright R. H. Rediker	J. Appl. Phys. <u>36</u> , 1574 (1965)
2460	Electrical Properties of Ferromagnetic $\text{CrO}_x$ ( $1.89 < x < 2.02$ )	D.S. Chapin* J. A. Kafalas J. M. Honig	J. Phys. Chem. <u>69</u> , 1402 (1965)
2464	Semiconductor Lasers	R. H. Rediker	Phys. Today <u>18</u> , No. 2, 42 (1965) (DDC 613892)
2474	Optical Pyrometer Measurement of RF Power	T. B. Reed J. T. Roddy	Rev. Sci. Instr. <u>36</u> , 620 (1965)
2475	Simple Construction for Determining the Phase Change of Light Reflected at Normal Incidence	G. B. Wright	Appl. Optics <u>4</u> , 366 (1965) (DDC 614309)
2477	Magnetoabsorption of the Indirect Transition in Germanium	J. Halpern B. Lax	J. Phys. Chem. Solids <u>26</u> , 911 (1965)
2505	Longitudinal Injection-Plasma Laser of InSb	I. Melngailis	Appl. Phys. Letters <u>6</u> , 59 (1965) (613903)
2506	Observation of Interband Transitions in Antimony	M. S. Dresselhaus J. G. Mavroides	Phys. Rev. Letters <u>14</u> , 259 (1965) (614312)
2510	Measurement of Amplitude Noise in Optical Cavity Lasers	C. Freed H. A. Haus*	Appl. Phys. Letters <u>6</u> , 85 (1965) (DDC 614737)
2511	Spin Density of s Electrons in Iron	T. A. Kaplan	Phys. Rev. Letters <u>14</u> , 499 (1965)
2515	Optically Pumped Semiconductor Laser	R. J. Phelan, Jr. R. H. Rediker	Appl. Phys. Letters <u>6</u> , 70 (1965) (DDC 613905)
2517	Properties of the PbSe Laser	J. F. Butler A. R. Calawa R. H. Rediker	IEEE J. Quant. Electron. <u>QE-1</u> , 4 (1965)
2528	S-Band GaAs Gunn Effect Oscillators	T. M. Quist A. G. Foyt	Proc. IEEE (Correspondence) <u>53</u> , 303 (1965)
2529A	GaAs-InSb n-n Heterojunction: A Single-Crystal "Schottky" Barrier	E. D. Hinkley R. H. Rediker D. K. Jadus*	Appl. Phys. Letters <u>6</u> , 144 (1965)

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\* Author not at Lincoln Laboratory.

Published Journal Articles (Continued)

## JA No.

General	Review: "On the Choice of Coordinates Used to Describe Thermoelectric and Thermo-magnetic Generators" by J. F. Osterle and S. W. Angrist	J. M. Honig	J. Appl. Mech. <u>31</u> , 565 (1964)
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MS No.			
985A	Experiments on Room Temperature Nernst-Ettinghausen Refrigerators	T. C. Harman J. M. Honig S. Fischler A. E. Paladino M. J. Button	J. Eng. Indust. (Trans. ASME <u>B</u> ) <u>87</u> , 21 (1965)
1010	On the Symmetry of Spin Configurations in Magnetic Crystals	J. O. Dimmock	Proc. International Conference on Magnetism, Nottingham, 7-11 September 1964 (DDC 614859)
1011	Injection Luminescence in InAs Diodes	I. Melngailis	Proc. Seventh International Conference on the Physics of Semiconductors — Radiative Recombination in Semiconductors, Paris, 27-28 July 1965
1013	Injection Luminescence and Laser Action in InSb	R. J. Phelan, Jr. R. H. Rediker	
1131	Electrical and Electro-Optical Properties of Interface-Alloy Heterojunctions	R. H. Rediker S. Stopek E. D. Hinkley	Trans. Met. Soc. AIME <u>233</u> , 463 (1965) (614320)
1172	Investigation of Eddy-Current-Induced Nondestructive Readout in Thin-Film Memories	M. S. Maltz	J. Appl. Phys. <u>36</u> , 1121 (1965)
1174	Complex vs Band Formation in Perovskite Oxides	J. B. Goodenough P. M. Raccah	J. Appl. Phys. <u>36</u> , 1031 (1965)
1175	Determination of Magnetic Ordering in Heisenberg Magnets from High-Temperature Expansions	T. A. Kaplan H. E. Stanley K. Dwight N. Menyuk	J. Appl. Phys. <u>36</u> , 1129 (1965)
1176	Magnetic Properties of $MnCr_2S_4$	N. Menyuk K. Dwight A. Wold	J. Appl. Phys. <u>36</u> , 1088 (1965)
1177	Diffuse Paramagnetic Neutron Scattering in Chromium Spinels	K. Dwight N. Menyuk T. A. Kaplan	J. Appl. Phys. <u>36</u> , 1090 (1965)
1242	Band Structure of Gadolinium Metal (Abstract)	J. O. Dimmock A. J. Freeman* R. E. Watson*	J. Appl. Phys. <u>36</u> , 1142 (1965)

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<sup>\*</sup> Author not at Lincoln Laboratory.

Published Journal Articles (Continued)

## JA No.

2542A	Optically Pumped InAs Laser	I. Melngailis	IEEE J. Quant. Electron. <u>QE-1</u> , 104 (1965)
2567	Electron Beam Pumped Lasers of PbS, PbSe, and PbTe	C. E. Hurwitz A. R. Calawa R. H. Rediker	IEEE J. Quant. Electron. <u>QE-1</u> , 102 (1965)

## UNPUBLISHED REPORTS

Journal Articles

## JA No.

2454	Resistivities and Transformation Rates of High-Pressure InSb- $\beta$ Sn Alloys	M. D. Banus L. B. Farrell A. J. Strauss	Accepted by J. Appl. Phys.
2473	Adsorption Theory from the Viewpoint of the Order-Disorder Theory	J. M. Honig	Accepted as Chapter 15 of <u>The Solid Gas Interface</u> (Marcell-Dekker, New York)
2480	Partial Pressures of Hg(g) and Te <sub>2</sub> (g) in the Hg-Te System from Optical Densities	R. F. Brebrick A. J. Strauss	Accepted by J. Phys. Chem. Solids
2495	The Effect of Trivalent Manganese on the Crystal Symmetry of Some Lithium Spinels	D. B. Rogers R. W. Germann R. J. Arnott	Accepted by J. Appl. Phys.
2501	Galvano-Thermomagnetic Phenomena and the Figure of Merit in Bismuth. II. Survey of Experimental Data and Calculation of Device Parameters	T. C. Harman J. M. Honig L. Jones*	Accepted by Adv. Energy Conversion
2509	Properties of Mercury Chalcogenides	T. C. Harman	Accepted as Chapter 15 of <u>Properties of II-VI Compounds</u> (North-Holland Publishing Company, Amsterdam)
2516	Chemical Inhomogeneities and Square B-H Loops	J. B. Goodenough	Accepted by J. Appl. Phys.
2518	Free Carrier Magneto-Optical Effects	E. D. Palik* G. B. Wright	Accepted as Chapter 1 of <u>Physics of III-V Compounds</u> , Vol. 2 (Academic Press, New York)
2520	The Relation of the Electrical Conductivity in Single Crystals of Rhenium Trioxide to the Conductivities of Sr <sub>2</sub> MgReO <sub>6</sub> and Na <sub>x</sub> WO <sub>3</sub>	A. Ferretti D. B. Rogers J. B. Goodenough	Accepted by J. Phys. Chem. Solids

\* Author not at Lincoln Laboratory.

Unpublished Journal Articles (Continued)

## JA No.

2523	Field Effect on Magnetoresistance of n-Type Indium Antimonide	S. Kawaji* H. Huff* H.C. Gatos	Accepted by Surface Sci.
2530	Preparation and Paramagnetism of the Rare Earth Trifluorides	S. Kern* P.M. Raccah	Accepted by J. Phys. Chem. Solids
2579	Impurity and Exciton Effects on the Infrared Absorption Edges of III-V Compounds	E.J. Johnson H. Y. Fan*	Accepted by Phys. Rev.
2580	Particle Sizes of Clay Minerals by Small-Angle X-Ray Scattering	R.J. Arnott	Accepted by Am. Mineralogist

Meeting Speeches<sup>†</sup>

## MS No.

1036E	Magnetoreflection Studies of the Band Structure of Semimetals	M. S. Dresselhaus	Colloquium, Northeastern University, 4 May 1964
1116A	The Breakdown of Ligand-Field Theory in Metallic Oxides	J.B. Goodenough	University of Pennsylvania, 22 March 1965
1210	The Chemical Analysis of In-Sb-Te Alloys	M.C. Gardels J.C. Cornwell	Conference on Analytical Chemical and Applied Spectroscopy, Pittsburgh, Pennsylvania, 1-5 March 1965
1235	Perturbation of the Refractive Index of Absorbing Media by a Laser Beam	P. R. Longaker M. M. Litvak	
1236	Experimental Dependence of PbSe Diode Radiation on Stress	A. R. Calawa J.F. Butler R.H. Rediker	
1237	Recombination Mechanism for Laser-Produced Discharges in Argon	D. F. Edwards M. M. Litvak	
1263	Interband Transitions in Pyrolytic Graphite at the Zone Corner	J.G. Mavroides M. S. Dresselhaus	
1264	Calculation of the Magnetic Susceptibility in Graphite	M. S. Dresselhaus S.J. Williamson* G. F. Dresselhaus	
1297	Anisotropy of the deHaas-Van Alphen Effect in Pyrolytic Graphite	S.J. Williamson* S. Foner* M. S. Dresselhaus	

American Physical Society,  
New York, 27-30 January 1965

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† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

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Unpublished Meeting Speeches (Continued)

## MS No.

1237A	Recombination Mechanism for Laser-Produced Discharges in Argon	D. F. Edwards	Optics Colloquium, University of Rochester, 24 February 1965
1243	Recent Advances in Semiconductor Lasers	R. H. Rediker	IEEE International Convention, New York, 22-25 March 1965
1246	Effects of Strain on Infrared Absorption Spectra of Sulfur Doped Silicon	W. E. Krag W. H. Kleiner S. Fischler H. J. Zeiger	American Physical Society, Berkeley, California, 21-22 December 1964
1248	Laser-Produced Gas Discharges	D. F. Edwards	American Chemical Society Annual Chemical Engineering Symposium on Lasers and the Chemical Industry, Detroit, Michigan, 4-9 April 1965
1267	Pb Salt Diode Lasers	J. F. Butler	Seminar, U.S. Naval Ordnance Laboratory, Silver Springs, Maryland, 25 January 1965
1271	The Gunn Effect in GaAs	A. G. Foyt A. L. McWhorter	
1272	Plasma Wave Transmission Through Bismuth	W. G. May A. L. McWhorter	
1273	Partial Pressures of Hg(g) and Te <sub>2</sub> (g) in the Hg-Te System	R. F. Brebrick A. J. Strauss	
1274	Band Structure and Fermi Surface of Magnesium	J. O. Dimmock A. J. Freeman* A. M. Furdyna*	
1275	Energy-Momentum Dispersion Relations for Antimony	G. F. Dresselhaus M. S. Dresselhaus J. G. Mavroides	American Physical Society, Kansas City, Missouri, 24-27 March 1965
1276	Electronic Energy Bands and Fermi Surface of Thulium	A. J. Freeman* J. O. Dimmock R. E. Watson*	
1277	Observation of Interband Transitions in Antimony	J. G. Mavroides M. S. Dresselhaus	
1278	Photoluminescence of GaAs in a High Magnetic Field	G. B. Wright F. L. Galeener*	
1279	Magneto-Emission Experiments with Pb Salt Diode Lasers	J. F. Butler A. R. Calawa R. H. Rediker	

\* Author not at Lincoln Laboratory.

## Unpublished Meeting Speeches (Continued)

MS No.			
1280	Recombination Mechanism for Laser-Produced Discharges. II. Helium and Hydrogen	D. F. Edwards M. M. Litvak	
1282	GaAs-InSb n-n Heterojunction: A Single-Crystal "Schottky" Barrier	E. D. Hinkley R. H. Rediker	American Physical Society, Kansas City, Missouri, 24-27 March 1965
1283	High Power Density Fluorescence of InSb in a Magnetic Field	R. J. Phelan, Jr. R. H. Rediker	
1298, 1298A	Metallic and Semiconducting Oxides	J. M. Honig	University of Arizona, 19 February 1965; Arizona State University, 19 February 1965
1304	Oscillatory Faraday Rotation of the Indirect Transition in Germanium	J. Halpern	American Physical Society, Washington, D.C., 26-29 April 1965
1311	A Self-Consistent Field Theory of Magnetism	G. F. Dresselhaus	Solid State Theory Seminar, Harvard University, 17 February 1965
1320	Stimulated Stokes and Anti- Stokes Processes	H. J. Zeiger	Solid State Seminar, University of Rochester, 2 March 1965
1329	TiO <sub>2</sub> as a Catalyst	J. M. Honig	Spring Conference, Amherst College, 23-24 April 1965
1331	Semiconductor-to-Metal Transition in Transition Metal Oxides	J. Feinleib	Materials Science Center Colloquium, M.I.T., 12 March 1965
1344	CW PbS Diode Laser	J. F. Butler A. R. Calawa	Electrochemical Society, San Francisco, 10-14 May 1965
1345	Solution Regrowth of Planar InSb Laser Structures	I. Meingailis A. R. Calawa	
1349	Nonlinear Optics in Solid State Research	P. L. Kelley	Physics Seminar, University of New Hampshire, 1 April 1965
1358	Magnetoreflection Experiment and the Band Structure of Antimony	M. S. Dresselhaus	Solid State Seminar, National Magnet Laboratory and M.I.T. 9 April 1965
1360	Electronic Band Structure of Rare-Earth Metals	J. O. Dimmock	Seminar, Naval Research Laboratory, White Oak, Maryland, 5 April 1965
1361	Generation of Stokes and Anti- Stokes Radiation in Raman Media	P. L. Kelley	Seminar, Tufts University, 9 April 1965

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MS No.

1363	Semiconductor Lasers	R. H. Rediker	American Physical Society, Worcester Polytechnic Institute, 17 April 1965
1375	K-P Theory of Semiconductors	J.O. Dimmock	Seminar, Brown University, 26 April 1965
1379	Growing Waves and Oscillations In Solids	A. L. McWhorter	Joint Physics Colloquium and Semiconductor Seminar, University of Illinois, 29 April 1965

## SOLID STATE DIVISION 8

### I. SOLID STATE DEVICE RESEARCH

Laser action has been achieved in optically pumped bulk samples of InSb, PbTe, and InAs. The required pump power densities were obtained by using the emission from a GaAs diode laser. Typically, the bulk homogeneous wafer to be pumped and the GaAs diode laser (separated by about 1 mm) were mounted on copper heat sinks in contact with liquid helium. The GaAs radiation was incident on an optically flat face of the wafer with a Fabry-Perot cavity formed by two cleaved faces perpendicular to the excited face; thus, the laser emission occurred in the direction perpendicular to the incident light. Assuming the creation of one electron-hole pair per photon absorbed in the excited samples, the thresholds for laser action are consistent with those obtained in diode lasers of the same semiconductor. Optical pumping has made possible the direct comparison of photoluminescent spectra of bulk homogeneous samples with laser spectra from these same samples. In n-InSb and n-InAs, the laser lines emanate from the band-to-band luminescent lines, whereas results indicate that, in p-InAs, the laser line is associated with transitions from the conduction band to zinc acceptor levels. Optical pumping of bulk InSb has been used to explain the reduction in threshold with magnetic field that has been reported for InSb diode lasers. The reduction occurs both because the magnetic field influences the carrier mobility, leading to a spatial concentration of the electron-hole pairs, and because it causes a condensation of states into Landau levels. Oscillatory magnetoemission in the photoluminescence has been observed as the Landau levels are tuned through the wavelength at which the intensity of the radiation is being monitored.

Laser action has been obtained at liquid helium temperature in crystals of PbS, PbSe, and PbTe excited by a beam of fast electrons. In all three materials, lasing was observed for electron energies from 19 to 60 kev. For PbSe, the threshold with 50 kev electrons occurs at a beam current density of  $7.1 \text{ ma cm}^{-2}$ . If one neglects backscattering and assumes that the mean energy to create a pair is  $3E_g$ , this threshold is equivalent to a diode laser threshold of about  $800 \text{ amp cm}^{-2}$ .

Cathodoluminescence has been observed at liquid helium, liquid nitrogen, and room temperatures in single crystals of the following materials: SiC,  $\text{Zn}_2\text{SiO}_4$ , Mn, ZnTe, ZnSe, ZnS, CdS, ZnO, GaSe. The emission spectra of all the SiC and GaSe samples were very broad (500 to 1000 Å) and showed no significant structure. In ZnTe, ZnSe, ZnS, CdS, and ZnO, the emission spectra showed a good deal of structure and generally consisted of one or more lines near the band gap energy, corresponding to direct recombination or recombination through shallow excitons or impurities. No stimulated emission as evidenced by line narrowing or strong superlinearity of intensity vs beam current was observed in any of these materials at beam current densities up to  $5 \text{ amp cm}^{-2}$  and beam voltages as high as 60 kev. Work is in progress.

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to reduce the spreading of the beam size at high currents as well as reduce sample heating which may also occur at these currents. Purer samples, as well as samples doped in a more controlled manner, of some of these materials will also be investigated.\*

A scanning beam laser has been constructed. Laser action was obtained by sweeping a GaAs strip with an electron beam. By cooling the GaAs strip with liquid helium or nitrogen, coherent radiation appeared at 45 and 60 kev electron energy and 0.2 and 0.5 amp  $\text{cm}^{-2}$  current densities, respectively.

Magnetoemission experiments have been performed with PbSe and PbTe diode lasers. Two emission lines are observed, and from comparison with magneto-absorption results can be identified with the two lowest energy transitions between the zero-order spin-split Landau levels. The emission line with the smaller magnetic field effect cannot be observed in magneto-absorption work because of the relatively high carrier concentrations which have been unavoidable in PbTe and PbSe. From this work, we obtain for PbTe and PbSe, respectively, reduced effective masses of 0.020 and 0.029, and g-values  $|g_v| = |g_c|$  of 35 and 21.

Threshold current densities for PbSe diode lasers at 4.2°K have been reduced, by improved fabrication techniques, from a previously reported value of 2000 amp  $\text{cm}^{-2}$  to as low as 200 amp  $\text{cm}^{-2}$ . Since at this temperature the diodes may be forward-biased with direct current densities of greater than 1000 amp  $\text{cm}^{-2}$  without overheating, CW laser action has been achieved at five times threshold current. The improved diodes exhibit laser action at 77°K, at which temperature threshold current densities of 1500 amp  $\text{cm}^{-2}$  have been measured.

Diode lasers have been fabricated of PbS by techniques similar to those for PbTe and PbSe. Threshold current densities at 4.2°K of 300 amp  $\text{cm}^{-2}$  have been achieved.

Lead salt lasers have been tuned by uniaxial pressure; a simple apparatus has been constructed to apply a known pressure to a sample which is both in a vacuum and at a temperature near 4.2°K.

We have obtained from GaAs Gunn-effect oscillators at room temperature, 2.5 watts of peak power at about 3 Gcps with a power efficiency of 7 percent. The devices were about 35 microns thick, had a top contact diameter of 270 microns, and a measured low field resistance of 5.2 ohms. They were fabricated from n-type GaAs which had a room temperature resistivity about 0.75 ohm-cm and mobility of  $5500 \text{ cm}^2 \text{ volt}^{-1} \text{ sec}^{-1}$ . The threshold voltage for these devices has been about 12 volts and the average current above threshold, 1 amp. The peak power and efficiency values listed above were obtained for an applied voltage of 35 volts. When operated much above 35 volts, the devices deteriorated and showed only a very low resistance and no instability.

Single-crystal junctions have been produced between wafers of GaAs and InSb by the interface-alloy technique, in spite of the very large lattice mismatch (14 percent) between these two zinc-blende semiconductors. The forward current of the GaAs-InSb n-n heterojunction varies with voltage as  $\exp[qV/nkT]$  with n very close to unity, whereas the reverse current varies as  $(V_D + V_{D_1} - kT/q)^{1/4}$ , where  $V_{D_1}$  is the GaAs diffusion potential; both functional dependences

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are as predicted by the Schottky emission theory. From current-voltage and capacitance-voltage measurements on these n-n heterojunctions as well as similar measurements on GaAs-InSb p-n, p-n, and n-p interface alloy heterojunctions, we have been able to deduce energy-band profiles for the GaAs-InSb heterojunctions, and explain why the transport properties of the n-n junctions are in agreement with Schottky emission theory. [At room temperature, the InSb band-gap (0.18 ev) is approximately eight times smaller than that of GaAs (1.38 ev).] The excellent reproducibility of characteristics afforded by these junctions (in contrast to most metal-semiconductor contacts), believed to originate in their single-crystalline nature, suggests attractive potentialities for the n-n junction in applications requiring Schottky-barrier devices.

## II. LASER RESEARCH

Multiple stimulated Brillouin shifts have been observed in quartz, and in a number of other materials, when excited by a 500-Mw ruby laser beam. In addition to several Stokes shifts, some of the emitted lines have been tentatively identified as anti-Stokes radiation. The Brillouin threshold is being measured as a function of scattering angle in order to utilize the lowest threshold for detection of the associated phonons.

Preliminary experiments show an 80-percent decrease of the threshold for stimulated Brillouin emission in both water and alcohol as the temperature is increased over a 20°C range up to the boiling points. This lowering of the threshold is, in part, attributed to a decrease of hypersonic absorption with temperature, as expected in these "associated liquids."

Rules have been derived for generation of sum and difference frequency in gases and liquids. In the electric dipole approximation, the contribution from the quadratic optical polarization vanishes unless the medium exhibits natural optical activity. Experiments of mixing the laser light with stimulated Raman-Stokes light are being considered in various configurations and media.

Second-harmonic generation by a Q-spoiled, focused ruby laser has been observed in silver at grazing incidence. Measurements are being made of the second-harmonic radiation for: polarization, angular distribution, percentage coherence, and dependence on the angle of incidence, focal length, and laser frequency.

Characteristics of the recombination of electrons in the laser-produced hydrogen plasma have been calculated from the observed time history of the plasma radiation. The line and continuum intensities give the electron temperature and density as a function of time. The experimental rate of density decrease agrees very well with theoretical estimates for the three-body (electron-electron-ion) recombination process.

Interferographs and shadowgraphs have been taken of the index changes due to the heating of absorbing liquids and gases by a laser beam. Although the observed thermal lens effects in the liquids are nearly as expected from the energy deposition, the index changes in monoethylamine gas are significantly weaker than expected. Q-switching the laser produces, in addition to the usual rarefaction effects, an outgoing cylindrical compression wave that has a density change of comparable magnitude, but opposite sign, to that in the illuminated region.

Experimental values have been obtained for the higher-order moments of the probability distribution of the photoelectron counts in a photomultiplier which is illuminated by a He-Ne

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laser, operating below but near threshold. These values are found to correspond to the output of a single narrow-band cavity mode, with an amplitude probability distribution which is Gaussian.

### III. MATERIALS RESEARCH

The arsenopyrites are a group of semiconducting compounds having the monoclinic structure of FeAsS and 19 outer electrons per formula unit. Not all members of the series have been prepared, and it was felt that high pressure might be useful for the synthesis of the missing members. Of the six compositions studied so far, only OsSbSe and OsSbTe have been obtained as pure, single-phase compounds. The compounds that contained bismuth gave incomplete and complex reactions. Preliminary results suggest a peritectic in the phase diagram under pressure.

Several rare-earth chromates  $R^{3+}Cr^{3+}O_3$  have been prepared and analyzed by x-ray.  $PrCrO_3$  has rhombohedral symmetry, all the others have orthorhombic perovskite structure. Since  $Pr^{3+}$  is of intermediate size, the change in structure is being influenced by some other property of the  $Pr^{3+}$  ion.

In experiments on the growth of camphor crystals by forced convection, the amount of supercooling required for crystal nucleation was found to be  $0.2^\circ C$ . The nondendritic growth velocity is approximately proportional to the amount of supercooling. At sufficiently high growth velocities, as in the case of iodine, dendritic growth occurs because of constitutional supercooling.

A new apparatus has been constructed for Czochralski growth of single crystals up to  $2200^\circ C$ . The tantalum resistance furnace has been redesigned to prevent the oxidation of the power leads which occurred in the previous apparatus. The instability of the growth interface, which formerly prevented the growth of crystals more than about an inch long, has been eliminated by using a water-cooled seed holder. The new apparatus has been used to grow single crystals of  $Ti_2O_3$  up to 3 cm in diameter and 6 cm long.

Single crystals of  $CoAl_2O_4$  and  $NiO$  have been successfully grown from fluxes of lead oxyfluoride. Crystals of  $UO_{2+x}$  ( $x \approx 0.12$ ) have been grown by electrolytic reduction from a flux of 9:1  $Na_2WO_4:WO_3$  at  $800^\circ C$ .

The optical absorption of  $CaF_2$  crystals containing  $Sm^{+3}$  and  $Y^{+3}$  ions has been measured before and after irradiation with 2.5-Mev electrons. Results of the measurements show that the fraction of  $Sm^{+3}$  ions reduced to  $Sm^{+2}$  is decreased by the presence of  $Y^{+3}$  ions. When  $Sm^{+3}$  and  $Y^{+3}$  ions are present in comparable concentrations, neither species is reduced by irradiation.

We previously designated the ternary compound in the pseudobinary  $InSb-InTe$  system as  $In_4SbTe_3$ . However, metallographic and x-ray diffraction studies on samples annealed at  $475^\circ C$  have shown, in agreement with the results reported by Deneke and Rabenau, that at this temperature the composition  $In_3SbTe_2$  lies within the homogeneity range of the compound, but  $In_4SbTe_3$  does not. Therefore, we have now adopted  $In_3SbTe_2$  as the nominal formula for the compound.

In order to show that the striking magnetic and crystallographic changes that occur in  $MnAs_{1-x}X_x$ , where  $X = P$  or  $Sb$ , are due to size effects alone, the first-order  $B8_1 \rightleftharpoons B31$  transition at the Curie temperature of  $MnAs$  was monitored, via its accompanying discontinuity in electrical resistance, as a function of pressure and temperature. A critical pressure for stabilization of the  $B31$  phase to lowest temperatures is anticipated. After an initial linear change at

about  $18^{\circ}\text{C}/\text{kbar}$  in the transition temperature with pressure, an abrupt stabilization of the B31 phase to lowest temperature appears, from preliminary measurements, to occur for  $p > 5$  kbars.

In order to check the hypothesis of alternate (111) planes of high-spin and low-spin cobalt (3+) in  $\text{LaCoO}_3$  in the neighborhood of  $500^{\circ}\text{C}$ , which was based on the space group  $\text{R}\bar{3}\text{m}$  reported in the literature for this compound, the intensities of the x-ray diffraction peaks were monitored from room temperature to  $1600^{\circ}\text{K}$ . It was found that below the first-order transition at  $1210^{\circ}\text{K}$ , the correct space group is  $\text{R}\bar{3}\text{c}$ , which does not support the hypothesis. The atomic volume and lattice c-parameter vary linearly with temperature, exhibiting a discontinuity at  $1210^{\circ}\text{K}$ . The lattice a-parameter has a more complicated variation with temperature. The transition at  $1210^{\circ}\text{K}$  does not change the translational symmetry (rhombohedral  $\rightleftharpoons$  rhombohedral) and is diffusionless. Although the volume contracts with increasing temperature at  $1210^{\circ}\text{K}$ , the phase with larger atomic volume is stabilized at nearly all temperatures. A discontinuity in the over-all Debye-Waller factor from 0.1 to 2.3 is compatible with a semiconducting  $\rightleftharpoons$  metallic transition, which had also been predicted. Measurements of resistivity vs temperature as a function of pressure confirmed this conjecture as well as lowering the transition from  $1210^{\circ}\text{K}$  at atmospheric pressure to  $835^{\circ}\text{K}$  at 50 kbars. A decrease in the effect of pressure at higher pressures suggests the existence of a triple point.

It is pointed out that spontaneous distortions to lower symmetry provide an operational criterion for distinguishing the character of the outer d electrons of transition-metal compounds. If the cations remain in the centers of symmetry of their anion interstices, the outer d electrons are localized electrons that can be described by ligand-field theory. If cation subarrays are displaced toward one another, each cation moving away from the center of symmetry of its anion interstice, then the outer cationic d electrons are in partially filled, cation-sublattice d bands in the high-temperature phase. If the cations are moved out of their centers of symmetry toward some of their anion near neighbors, the covalent mixing of cationic d orbitals and anionic s-p orbitals approaches the critical amount for band vs localized orbitals.

Single crystals of intermediates in the system  $\text{Co}_{1+x}\text{V}_{2-x}\text{O}_4$  from fluxes of  $\text{Na}_2\text{WO}_4$ - $\text{WO}_3$  have exhibited Seebeck coefficients similar to those obtained from polycrystalline samples, but activation energies for conduction that are significantly smaller. However, a single crystal of  $\text{MgV}_2\text{O}_4$ , grown from the melt, had an activation energy for conduction similar to the polycrystalline sample. Also, the activation energies for the system  $\text{Co}_{1+x}\text{V}_{2-x}\text{O}_4$  extrapolate to the polycrystalline value for the end member  $\text{CoV}_2\text{O}_4$ . Therefore, our previous conclusions about the magnitude of the critical cation-cation separation for collective vs localized electrons, which were obtained from polycrystalline data for the spinels  $\text{M}^{2+}[\text{V}_2^{3+}\text{O}_4]$ , appear to be valid.

The Seebeck coefficient, resistivity, Hall coefficient, and magnetoresistance of two oriented, single-crystal samples of  $\text{Ti}_2\text{O}_3$  have been measured as a function of temperature. A tentative band model has been suggested to account for the temperature dependence of these properties.

$\text{LaInO}_3$  was expected to be a wide-gap semiconductor with a least-stable filled band that is narrow, consisting largely of cationic d orbitals. It was hoped that these narrow bands would be sufficiently unstable that they could be p-doped p-type rather than exhibit chemical compensation. Samples doped with Pd, Sr, and Th all had resistivities that were too high to allow determination of the sign of the charge carriers, but exhibited intrinsic and extrinsic temperature regions typical of broad-band semiconductors. The intrinsic energy gap is  $2.2 \pm 0.1$  ev.

The room temperature resistivity of  $Hg_{1-x}Cd_xTe$  alloys containing between 0 and 40 mole % CdTe has been measured as a function of hydrostatic pressure up to 6 kbars. The initial slope of the relative resistivity vs pressure curve,  $d\rho/\rho_0 dP$ , increases from  $\sim 0$  for pure  $HgTe$  to a maximum of  $\sim 0.2 \text{ kbar}^{-1}$  at about 20 mole % CdTe and then decreases to  $\sim 0$  near 40 mole % CdTe. This behavior is probably associated with the semimetal-semiconductor transition in these alloys, which is believed to occur at about 20 mole % CdTe.

Wet chemical methods accurate to within 0.2 percent of the reported values have been developed for the determination of indium and bismuth in In-Bi samples and for the determination of cobalt and vanadium in cobalt vanadium oxides. The polarographic method developed earlier for analysis of  $Hg_{1-x}Cd_xTe$  alloys has been modified to increase its speed and accuracy. A method has been developed for determining Cd in  $Hg_{1-x}Cd_xTe$  alloys by electron microprobe analysis.

#### IV. PHYSICS OF SOLIDS

Spin wave resonance experiments at room temperature in a number of permalloy films have been used to establish the presence of the quartic term in the spin wave dispersion relation in addition to the usual quadratic term. From the ratio of these two terms, it is concluded that the range of exchange interaction between spins is substantially greater than the nearest-neighbor distance; this is in agreement with the results of a previous experiment at low temperatures.

In an effort to select the most promising samples of PbSe for Azbel-Kaner resonance measurements, the size of the Shubnikov-de Haas effect is being used as a guide. Also, very stringent surface preparations are being observed. Preliminary Azbel-Kaner resonance results on p-type PbSe indicate that they cannot be explained on the basis of simple theory.

Preliminary observations have been made of paramagnetic resonance in powdered samples of  $Co^{2+}$  in  $ZnAl_2O_4$  and  $Zn_2SiO_4$  at  $4.2^\circ K$  and 35 kMcps. Thus far, the resolution has not been sufficient to determine the hyperfine splittings accurately. This hyperfine interaction will be used to establish the value of the effective field for NMR of  $Co^{2+}$  in the magnetic spiral system  $CoCr_2O_4$ .

Epitaxial CdS films have indicated transducer efficiencies at 1 Gcps at least comparable to those of x-cut quartz. Preliminary tests have also been made at 70 Gcps, but the results so far are inconclusive.

The lattice symmetry of the perovskite  $LaCoO_3$  has been investigated by neutron diffraction at room temperature and  $\sim 7^\circ K$ . The results at both temperatures were essentially similar; therefore, the departure of the susceptibility curve from linearity at  $\sim 80^\circ K$  cannot be attributed to the onset of ferromagnetism.

An exact quantization rule has been obtained, of a form similar to the semiclassical Bohr quantization rule for general one-dimensional periodic motion. For a simple harmonic oscillator, the exact quantization result becomes identical with the Bohr quantization rule.

The temperature-dependent Hartree-Fock equation, which has been used in the past, has been obtained on the basis of a variational principle. The variational principle involves the free energy of the system, where the usual Hartree-Fock approximation for the ground state involves the energy of the system.

A generalization of the Rudermann-Kittel-Kasuya-Yosida interaction has been obtained, for the non-spherical Fermi surfaces. The result is an asymptotic expansion in  $1/R$ , which is, in general, anisotropic, and which reduces to the exact (RKKY) result for spherical surfaces.

A method has been found for obtaining a manifestly gauge-invariant expression for the quantum-mechanical current excited by electromagnetic potentials acting on an ensemble of electrons.

The symmetry properties of the linear transport coefficients of a very general class of crystals has been considered, in the presence of external magnetic fields. It has been found that the usual Onsager relations do not apply generally to magnetic crystals, and appropriate generalized Onsager relations have been obtained.

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13. ABSTRACT    This is the first Quarterly Technical Summary on the General Research Program at Lincoln Laboratory, M. I. T.; it consolidates the material formerly published in the Quarterly Progress Reports of Divisions 2 (Data Systems), 3 (Radio Physics), 4 (Radar), 7 (Engineering), and 8 (Solid State).  The objective in making this change is to provide a more usable and efficient document, one that better shows the relationships among the General Research activities at this Laboratory.		
14. KEY WORDS  data systems      control research      range measurements digital computers      radio physics      microwave equipment computer components      space surveillance      solid state physics psychology      radar		